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Evaluation of Particulate Matter Control Equipment for Copper Smelters

PEDCo-Environmental, Inc, Cincinnati, Ohio

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16. Abstracts In 1977 at the request of EPA, Region IX, Enforcement Division, PEDCo Environmental, Inc. conducted an investigation of particulate matter control equipment which could be installed at two copper smelters located in Arizona. The two smelters investigated were the New Cornelia Branch copper smelter of the Phelps Dodge Corporation located in Ajo, Arizona and the Magma Copper Company copper smelter located in San Manuel, Arizona. The purpose of the investigation was to determine the technical feasibility of compliance and the cost of control equipment necessary to comply with the particulate matter control regulation. Fabric filters, scrubbers, dry and wet electrostatic precipitators were investigated with the assistance of Industrial Gas Cleaning Institute member companies (through Task 2 of EPA Contract No. 68-02-7532, Office of Air Quality Planning and Standards, Strategies and Air Standards Division). This report includes a description of each smelter; an analysis of available emission data for each smelter; and a summary of capital costs, annual costs and technical control equipment data for 9 control options for each smelter.

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Scrubber

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EPA Methods 5 and 8
Dry Electrostatic Precipitator
Air Pollution

Sulfur Trioxide
Fabric Filter
Wet Electrostatic Precipitator

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Contract No. 68-01-4147
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This interim report was prepared under the direction of Mr. Timothy W. Devitt. Mr. Lario Yerino was the Project Manager and Mr. Vishnu S. Katari was the Assistant Project Manager. Messrs. Vishnu S. Katari and Edmund S. Schindler were the principal investigators of this report. Task Manager for the U.S. Environmental Protection Agency was Mr. Larry Bowerman.

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TABLE OF CONTENTS

	Page
SUMMARY	x
1.0 INTRODUCTION	1-1
2.0 PLANT AND PROCESS DESCRIPTIONS	2-1
2.1 Magma Copper Smelter - San Manuel, Arizona	2-1
2.2 Phelps Dodge Copper Smelter - Ajo, Arizona	2-7
3.0 EMISSIONS AND CONTROLS	3-1
3.1 Analysis of Electrostatic Precipitator Performance Data on Reverberatory Furnace at Magma Copper Company, San Manuel, Arizona	3-1
3.2 Analysis of Electrostatic Precipitator Performance Data on Reverberatory Furnace at Phelps Dodge Corporation, Ajo, Arizona	3-10
4.0 ADD-ON CONTROL SYSTEM FOR PARTICULATE EMISSIONS	4-1
4.1 Add-On Control Systems for Magma Copper Company, San Manuel, Arizona	4-6
4.2 Add-On Control Systems for Phelps Dodge Corporation, Ajo, Arizona	4-30
APPENDIX A - Conversion Factors	A-1
APPENDIX B - Technical Specification for Add-On Control Systems for Reverberatory Furnace at Magma Copper Company, San Manuel, Arizona	B-1
APPENDIX C - Technical Specifications for Add-On Control Systems for Reverberatory Furnace at Phelps Dodge Corporation Ajo, Arizona	C-1
APPENDIX D - New Source Performance Standards for Primary Copper Smelters and EPA Process Weight Regulation	D-1
APPENDIX E - Trip Report - Visit to Magma Copper Company San Manuel, Arizona on 7/22/77	E-1

LIST OF FIGURES

No.		Page
2-1	Simplified process flow diagram of Magma Copper Company plant, San Manuel, Arizona	2-2
2-2	Process flow diagram for Phelps Dodge Corporation plant, Ajo, Arizona	2-11
3-1	Average inlet and outlet particle size distributions, particle size vs. cumulative percent, for the ESP at the Phelps Dodge smelter	3-33
3-2	Measured and theoretical fractional efficiency curves prepared by SRI for the ESP on the reverberatory furnace at Phelps Dodge Corporation	3-34

LIST OF TABLES

No.		Page
1	Capital and annual operating costs for add-on control systems on Magma Copper smelter	xi
2	Capital and annual operating costs for add-on control systems on Phelps Dodge smelter	xii
2-1	Smelter process equipment and operating data for Magma Copper Company, San Manuel, Arizona	2-3
2-2	Reverberatory furnace air pollution control equipment and operating data, Magma Copper Company - San Manuel, Arizona	2-4
2-3	Chronology of enforcement actions - Magma Copper Company, San Manuel, Arizona	2-8
2-4	Smelter process equipment and operating data - Phelps Dodge Corporation, Ajo, Arizona	2-12
2-5	Reverberatory furnace air pollution control equipment and operating data, Phelps Dodge Corporation - Ajo, Arizona	2-13
2-6	Chronology of enforcement actions - Phelps Dodge Copper Company, Ajo, Arizona	2-18
3-1	Summary of particulate emission data for electrostatic precipitator on reverberatory furnace - Magma Copper Company, San Manuel, Arizona	3-2
3-2	Particulate emission data	3-5
3-3	Analysis of metallic elements in gas sample run 2	3-6
3-4	Sulfur dioxide emissions	3-7

LIST OF TABLES (continued)

No.		Page
3-5	Summary of particulate emission data for electrostatic precipitator in reverberatory furnace - Phelps Dodge Copper smelter, Ajo, Arizona	3-11
3-6	Summary of the sampling effort (July 7 through July 16, 1976) by radian	3-14
3-7	Instack vs. outstack particulate loading Phelps Dodge Corporation, Ajo, Arizona	3-18
3-8	Analyses of total particulate and vapor phase particulate in flue gas at ESP inlet or outlet (by Radian Corporation)	3-21
3-9	Element flow rates in the feed and discharge streams of reverberatory furnace	3-22
3-10	Summary of sampling times - reverberatory ESP	3-25
3-11	Total solid input to the reverberatory furnace during shift "A" (8-hr period) on July 26, 1976 (estimated by the Phelps Dodge staff)	3-27
3-12	Summary of sampling data using EPA methods 3 and 4 - Phelps Dodge reverberatory furnace ESP	3-28
3-13	Summary of particulate, SO_3/H_2SO_4 and SO_2 emission data for reverberatory furnace ESP	3-29
3-14	Test results - sulfur oxide concentration	3-36
4-1	Design parameters of add-on control fabric filter system for Magma Copper smelter	4-8
4-2	Capital cost data for add-on control fabric filter system for Magma Copper smelter	4-10
4-3	Annual operating cost data for add-on fabric filter for Magma Copper smelter	4-11
4-4	Add-on control scrubber system design parameter for Magma Copper smelter	4-13

LIST OF TABLES (continued)

No.		Page
4-5	Capital cost data for add-on control scrubber system for Magma Copper smelter	4-17
4-6	Annual operating cost data for add-on control scrubber for Magma Copper smelter	4-19
4-7	Design parameters of add-on dry electrostatic precipitator system for Magma Copper smelter	4-22
4-8	Capital cost data for add-on dry electrostatic precipitator system for Magma Copper smelter	4-23
4-9	Annual operating cost data for add-on control dry electrostatic precipitator for Magma Copper smelter	4-24
4-10	Add-on control wet electrostatic precipitator system design parameters for Magma Copper smelter	4-26
4-11	Capital cost data for add-on wet electrostatic precipitator system for Magma Copper smelter	4-28
4-12	Annual operating cost data for add-on wet electrostatic precipitator for Magma Copper smelter	4-29
4-13	Design parameters of an add-on fabric filter system for the Phelps Dodge Corporation smelter in Ajo, Arizona	4-32
4-14	Capital cost data for add-on control fabric filter system for Phelps Dodge Corporation smelter	4-35
4-15	Annual operating cost data for add-on control fabric filter for Phelps Dodge Corporation smelter	4-37
4-16	Design parameters of add-on scrubber system for Phelps Dodge Corporation smelter	4-40

LIST OF TABLES (continued)

No.		Page
4-17	Capital cost data for an add-on scrubber system for Phelps Dodge Corporation smelter	4-43
4-18	Annual operating cost data for add-on scrubber for Phelps Dodge Corporation smelter	4-44
4-19	Design parameters for add-on dry electrostatic precipitator for Phelps Dodge Corporation smelter	4-46
4-20	Capital cost data for add-on dry electrostatic precipitator system for Phelps Dodge Corporation smelter	4-48
4-21	Annual operating cost data for add-on control dry electrostatic precipitator for Phelps Dodge Corporation smelter	4-49
4-22	Design parameters of an add-on control wet electrostatic precipitator system for the Phelps Dodge Corporation smelter	4-51
4-23	Capital cost data for an add-on wet electrostatic precipitator system for Phelps Dodge Corporation smelter	4-55
4-24	Annual operating cost data for Add-on control wet electrostatic precipitator for Phelps Dodge Corporation smelter	4-57

SUMMARY

The Magma Company smelter at San Manuel, Arizona, and the Phelps Dodge smelter at Ajo, Arizona, are not in compliance with the EPA Process Weight Regulation 40 CFR 52.126(b), according to EPA Test Method 5.

Substantial technology was available to the copper industry in 1973 to comply with EPA Process Weight Regulation 40 CFR 52 126(b). It is possible for these smelters to achieve compliance with this regulation by applying control technology that is presently available. The following add-on control systems could be installed in series with the existing ESP's at the subject smelters:

1. Gas cooling equipment to reduce flue gas temperature to 120°C (250°F) and a dry ESP to reduce the flue gas dust loading to an allowable level;
2. Gas cooling equipment to reduce flue gas temperature to 120°C (250°F) and a wet ESP to reduce the flue gas dust loading to an allowable level;
3. Gas cooling equipment to reduce flue gas temperature to 120°C (250°F) and a fabric filter to reduce the flue gas dust loading to an allowable level;
4. Gas cooling equipment to reduce flue gas temperature and a wet scrubber system to reduce the flue gas dust loading to an allowable level.

Tables 1 and 2 present estimated capital costs and annual operating costs of the add-on control systems for Magma Copper Company and Phelps Dodge Corporation, respectively. Magma Copper's add-on control system costs are based on

Table 1. CAPITAL AND ANNUAL OPERATING COSTS FOR ADD-ON CONTROL SYSTEMS ON MAGMA COPPER SMELTER

System Description	Evaluation	Turnkey Capital Cost, $	Annual Operating Cost,[a] $
1) Spray water cooling of gas to 120°C (250°F), fabric filter followed by a fan	A	6,168,300	1,345,700
2) Air dilution of gas to 120°C (250°F), fabric filter followed by a fan	B	15,607,000	4,468,000
3) Two units, each containing a quencher, an adjustable venturi, a flooded elbow, and a mist eliminator followed by two fans	C	4,824,100	4,466,100
4) Two units, each with a fan and a separate quencher followed by a venturi scrubber	D	3,986,000	2,762,800
5) One unit scrubber system consisting of a prequench section, a venturi, and a separator section followed by a fan	E	5,090,000	1,685,500
6) Two parallel systems, each containing a fan, a cooling system, and an ESP	F	6,665,500	1,604,000
7) Two parallel systems each containing a fan, a cooling system, and an ESP	G	8,441,200	2,072,900
8) Two parallel systems each containing a fan, a cooling system, and an ESP	H	7,378,900	1,633,500
9) Two parallel systems consisting of a fan, an evaporative cooling tower, and a WEP	I	6,990,400	2,147,100

a) Includes operating cost and fixed capital charges.

Table 2. CAPITAL AND ANNUAL OPERATING COSTS FOR ADD-ON CONTROL SYSTEMS ON PHELPS DODGE SMELTER

	System Description	Evaluation	Turnkey Capital Cost, $	Annual Operating Cost,[a] $
1)	Spray water cooling of gas to 120°C (250°F), fabric filter followed by a fan	J	2,003,200	586,600
2)	Air dilution of gas to 120°C (250°F), fabric filter followed by a fan	K	3,960,800	1,062,700
3)	An adjustable throat venturi, a flood elbow, and an entrainment separator, followed by a fan	L	724,300	878,600
4)	A prequencher, an adjustable-throat venturi scrubber, and a separator section followed by a fan	M	842,800	914,000
5)	A prequencher, an adjustable-throat venturi scrubber, and a separator section followed by a fan	N	2,056,800	745,400
6)	A fan, an evaporative cooling tower to cool gas to 120°C (250°F), followed by a dry ESP	P	1,933,800	621,000
7)	A fan, a combination of heat exchanger and dilution air to cool gas to 120°C (250°F) and two dry ESP's in parallel	Q	2,452,400	626,900
8)	A fan, a spray water tower to cool gas to 120°C (250°F) and a dry ESP	R	1,734,700	429,400
9)	A fan, an evaporative cooling tower followed by a WEP	S	2,023,400	564,500

a) Includes operating cost and fixed capital charges.

electrostatic precipitator outlet gas flow conditions of 18,264 m^3/min (645,000 acfm) at 300°C (573°F) and an average of 1.76 g/m^3 (0.77 gr/scf) and a maximum of 2.86 g/m^3 (1.25 gr/scf) particulate content measured at 120°C (250°F). The system is sized for a minimum of 98.2 percent control efficiency. The Phelps Dodge add-on control system costs are based on outlet gas flow conditions of 5270 m^3/min (186,000 acfm) at 314°C (598°F) and an average of 1.28 g/m^3 (0.56 gr/scf) and a maximum of 3.14 g/m^3 (1.37 gr/scf) particulate content measured at 120°C (250°F). This system is sized for a minimum of 93.0 percent control efficiency.

The following conclusions are based on a review of the information available on particulate testing on the reverberatory furnace control systems at the Phelps Dodge Copper Company, Ajo, Arizona, and Magma Copper Company, San Manuel, Arizona.

Magma Copper Company, San Manuel

NEIC tested emissions from the reverberatory furnace stacks for particulate compliance; they also did some ancillary testing to evaluate the effect of temperature on particulate formation. Prior to NEIC testing, Magma also tested emissions from the reverberatory furnace stack. However, since proper isokinetic conditions were not maintained during the company testing, these test results cannot be considered valid.

The following is a brief summary of NEIC test results:

1. Three compliance test measurements by NEIC on May 14 to May 22, 1976, indicate that the reverberatory furnaces emitted an average of 989 kg/hr (2180 lb/hr) of particulate, which is over 50 times the allowable 18 kg/hr (39.7 lb/hr) for the observed process weight rates. Data are not available on ESP dust collection during the testing; however, company data show an average of 113.4 metric tons (125 tons) per day were being recycled from both the reverberatory and converter electrostatic

precipitators to the reverberatory furnaces. This indicates that the electrostatic precipitator efficiency, measured according to EPA Method 5, is lower than the design efficiency, which is based on ASME test method.

2. Stack volume flow rates are about 15 percent higher than volume flow design of the electrostatic precipitator.

3. Average sulfur dioxide and sulfur trioxide emissions during compliance testing were 5400 ppm (8083 kg/hr or 17,820 lb/hr) and 15.0 ppm (30 kg/hr or 66.1 lb/hr), respectively. The measured sulfur dioxide and sulfur trioxide emissions during ancillary testing were 2600 to 5000 ppm and 31 to 93 ppm, respectively.

4. During the compliance tests with an inert glass probe liner, no sulfates were found in the filter or acetone catches. However, ancillary tests showed that particulate sulfate appears to be formed as the reverberatory furnace gases pass through the instack filter and glass frit support (a considerable amount of sulfate was deposited on the outstack filter). Measured values of moisture content in the gas averaged 8 percent. Because of the 8 percent average moisture content of the gases, NEIC believes that most of the sulfur trioxide would be in the form of sulfuric acid mist (H_2SO_4) at a temperature of (120° ± 14°C) (248° ± 25°F). However, it is possible that some or all of the sulfuric acid would be in the gaseous form rather than the liquid (mist) form.

5. No data are available on metallic elements in the gases other than one measured analysis at the ESP outlet. Copper, arsenic, and zinc were the principal elements detected in the analysis of the reverberatory furnace stack gas.

6. Most of the arsenic was collected on the filter during the compliance tests. The amount collected in the impinger was negligible.

Phelps Dodge Copper Company, Ajo

Radian Corporation, Southern Research Institute, and Aerotherm Corporation conducted the testing. The following is a brief summary of the results:

1. Particulate matter in the gases released from the furnace is very cohesive and hygroscopic.

2. Apparently, chemical composition differs with particulate size. The ESP inlet and outlet particulate size distribution is bimodal. The mass median diameter of the inlet particle size distribution was greater than 10 µm. One component of the bimodal inlet particulate distribution had a mass median diameter less than 1 µm.

3. The ESP may be handling volumes more than 10 percent over design rate.

4. It may be necessary to find out how loadings vary as a function of furnace operation cycle. Three test runs by Radian Corporation on July 15, 1976, using an instack/outstack filter train determined a particulate emission rate of 323 kg/hr (712 lb)/hr at the ESP outlet. However, two test measurements by Aerotherm on July 29 and 30, 1976, determined the particulate emission rate at the ESP outlet to be 192.1 kg/hr (423.5 lb/hr). Approximately the same amount of input material was charged to the furnace during these tests.

5. The difference in dust loadings in the gas through the two parallel inlet ducts leading to the ESP is significant according to several measurements by Radian Corporation. Both Radian Corporation and SRI reached the conclusion that gas velocity distribution is good.

6. Only Aerotherm Corporation particulate sampling test results are based on EPA Test Method 5. The average of seven particulate emission measurements on the ESP outlet was 129.5 kg/hr (285.4 lb/hr) (extrapolated weight) and the corresponding allowable emission rate was 14.2 kg/hr (31.2 lb/hr). Therefore, compliance with the EPA particulate emission regulation requires the installation of an additional control system with an

89.07 percent efficiency [measured at 120°C (250°F)] in series with the existing ESP [designed to operate at 98.8 percent efficiency at 316°C (600°F)].

7. During the three tests by Radian Corporation, the particulate collection on the outstack filter at 120°C (250°F) was about 96.0 percent of the total collected by the instack/outstack train. However, the corresponding measurements in two runs by Aerotherm determined that only 50 percent of the total particulate is collected on the outstack filter of the instack/outstack filter train. This difference could be due to the fact that Aerotherm included the probe wash with "instack particulate," whereas Radian included the probe wash with "outstack" particulate. The Radian definition is the most logical.

8. It is not clearly explained why consistently higher amounts of particulate are collected using instack/outstack filter train than using only an outstack filter according to EPA Method 5. An average of 129.5 kg/hr (285.4 lb/hr) particulate was measured during seven test runs using EPA Method 5, and an average of 192.2 kg/hr (423.8 lb/hr) particulate was measured during two test runs by Aerotherm using instack/outstack filter train.

9. Arsenic in the gas is present as arsenolite.

10. Nearly all of the arsenic, 50 percent of the selenium, and 30 percent of fluorine are discharged together with the reverberatory furnace off-gases. Arsenic and selenium escaping the electrostatic precipitator are partly in the vapor state, and nearly all of the fluorine escapes in a gaseous state. Radian tests on an ESP inlet and outlet wet electrostatic precipitator showed that only about 28 percent of arsenic measured at atmospheric temperature is collected by the existing ESP. Almost all the arsenic collected in the ESP at the outlet was present as condensed material. Arsenic measurements by Radian at 120°C (250°F), using EPA Method 5, also showed the efficiency of the existing ESP for arsenic to be about 28 percent.

11. Measurement of particulate collection efficiency of waste-heat boilers will help to define emission characteristics of copper reverberatory furnace gases. According to Radian Corporation measurements of the total 86.2 kg/hr (190 lb/hr) of arsenic entering the furnace, about 0.73 kg/hr (1.6 lb/hr) is present in matte, 0.86 kg/hr (1.9 lb/hr) in slag, 34.5 kg/hr (76 lb/hr) in the ESP outlet, and 13.6 kg/hr (30 lb/hr) in ESP hopper. Another test measurement showed 63.5 kg/hr (140 lb/hr) arsenic in the ESP off gases. That means about 8 to 40 percent of the total arsenic in the furnace gases may be precipitating in the waste-heat boilers and flue leading to the ESP.

1.0 INTRODUCTION

As a result of Petitions for Review filed by the Magma Copper Company and Phelps Dodge Corporation, the Enforcement Division of Region IX of the U.S. Environmental Protection Agency (EPA) is coordinating a study of copper smelters in the region. The purpose of this study is to review and analyze the basis for and the reasonableness of the EPA Process Weight Regulation [40 CFR 52-126(b)] as it applies to the Magma smelter in San Manuel, Arizona; to the Phelps Dodge copper smelter in Ajo, Arizona; and generally to all copper smelters in Region IX.

EPA Region IX provided us with the following documents which contain emission data of existing control systems on the smelters at Magma Copper Company and at Phelps Dodge Corporation:

1. National Enforcement Investigations Center and Region IX. Emission Testing at the Magma Copper Company Smelter, San Manuel, Arizona, May 12-22, 1976. EPA-330/2-76-029, U.S. Environmental Protection Agency, August 1976.

2. National Enforcement Investigations Center. Ancillary Tests at Magma Copper Company Smelter, San Manuel, Arizona, conducted on May 14-18, 1976.

3. Chronology of Enforcement Actions by EPA on Magma Copper Company, San Manuel, Arizona.

4. Environmental Protection Agency. State Implementation Plan Inspection of Phelps Dodge Corporation New Cornelia Branch Smelter, Ajo, Arizona. May 1976.

5. Radian Corporation. Trace Element Study Around the Reverberatory Furnace and the Electrostatic Precipitator of a Primary Copper Smelter (Preliminary draft). EPA Contract 68-01-4136, U.S. Environmental Protection Agency, Cincinnati, Ohio, May 9, 1977.

6. Acurex Corporation/Acrotherm Division. Stack test results at Phelps Dodge Corporation, Ajo, Arizona. EPA-68-01-3158, U.S. Environmental Protection Agency, Region IX, San Francisco, California 94111, March 1977.

7. Chronology of Enforcement Actions by EPA on Phelps Dodge Corporation, Ajo, Arizona.

8. Southern Research Institute. Performance Evaluation of an Electrostatic Precipitator Installed on a Copper Reverberatory Furnace. EPA Order No. CA-6-99-2980-J, U.S. Environmental Protection Agency, IERL, Cincinnati, Ohio, January 14, 1977.

From time to time EPA Region IX also supplied additional information as requested.

It should be noted that many of these documents contain data on tests conducted for compliance purposes, and they lack information on conditions at the inlet of the smelter control systems. These data can be used to evaluate additional control requirements for the smelters' compliance with the process weight regulation. They are, however, insufficient to determine any new control system alternatives for smelter compliance.

Based on available information of the process weight rates to the reverberatory furnace, the allowable emission rates have been determined by the process weight regulation 40 CFR 52.126(b) for the Magma Copper Company and Phelps Dodge Corporation. Using emission test data on the existing control system exit and on the allowable emission rate, the required additional control efficiency has been estimated.

After discussing available emission test data with members of the Industrial Gas Cleaning Institute (IGCI), it was decided to evaluate dry and wet electrostatic precipitators, fabric filters, and wet scrubbers as an add-on control system for each smelter. The process weight regulation requires the flue gas particulate content to be measured at about 120°C (250°F). When the flue gas temperature is reduced from a higher temperature to about 120°C (250°F), its particulate matter consists of material that has condensed from the vapor phase to the solid phase. For these reasons it was also decided to cool the gas from the existing control system to 120°C (250°F) before treating it in an additional system.

Specifications for each add-on control system on individual smelters were prepared on the basis of emission data from available reports. The data included such information on inlet conditions as gas volume flow rate, temperature, moisture content, gas composition, and particulate size analysis, as well as the required control efficiency and the allowable emission rates. The specifications were sent to selected IGCI members with a request for capital and annual operating cost data and design data for the add-on controls. These data were tabulated.

PEDCo Environmental, Inc., inspected the operation, existing control equipment, and space available in the vicinity of each smelter.

Section 2.0 of the report describes the reverberatory furnace process and control systems of the Magma and Phelps Dodge copper smelters. The section also presents the chronology of EPA enforcement actions on these smelters.

Section 3.0 summarizes emission test data obtained from the available documents.

Section 4.0 presents evaluations of the different add-on control systems designed for the compliance of the smelters under discussion. The evaluations cover two fabric filters, three wet scrubbers, three dry electrostatic precipitators, and one wet electrostatic precipitator for each smelter. The evaluations present the design parameters, capital costs, and annual operating costs for each system. The fabric filter costs include a gas cooling system, fabric filter, necessary ductwork, and fan; the scrubber system costs include a gas cooling system, scrubber, wet particulate waste treatment equipment necessary duckwork, and fan; and the dry and wet electrostatic precipitator costs include a gas cooling system, precipitator, necessary ductwork, and fan but do not include dry waste treatment (or disposal) equipment.

Appendix A is a table for converting English into metric units. Appendix B and Appendix C contain the add-on control system specifications for Magma Copper Company and Phelps Dodge Corporation, respectively. Appendix D contains the New Source Performance Standards for Primary Copper Smelters, the EPA Process Weight Regulation for existing copper smelters in the Phoenix - Tucson Air Quality Control Region, the EPA Test Methods 1-8 and the ASME "Test Code For Determining The Dust Concentration in a Gas Stream." Appendix E contains memorandums on the PEDCo's trips to the Magma Copper company and Phelps Dodge Corporation.

2.0 PLANT AND PROCESS DESCRIPTIONS

2.1 MAGMA COPPER SMELTER - SAN MANUEL, ARIZONA*

2.1.1 Plant Description

The Magma Copper Company operates an underground mine, concentrator, smelter, electrolytic refinery, and continuous casting rod plant in the vicinity of San Manuel, Arizona. Products include electrolytically refined copper, copper rod, sulfuric acid, and molybdenum. Average anode copper production averages 613 to 635 metric tons (675 to 700 tons) per day.

Figure 2-1 is a simplified process flow diagram of the Magma smelter. Table 2-1 lists the major smelter process equipment and operating data, and Table 2-2 describes and provides operating data on the electrcstatic precipitator (ESP's) used for air pollution control.

Concentrate is conveyed by belt from the concentrator to storage bins above the three reverberatory furnaces at the smelter. Limerock is added to the concentrate in the storage bins, and silica rock is stored in adjacent bins. The concentrate and flux (limerock or silica rock) are moved by belt conveyor from the storage bins to hoppers above and adjacent to the side walls of the three reverberatory furnaces. Charging doors are opened and the material is fed to the reverberatory furnaces by gravity flow.

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* This discussion is based mainly on information from Emission Testing at the Magma Company Shelter, San Manuel, Arizona, by the National Enforcement Investigations Center. EPA-330/2-76-029. May 2-22, 1976. Figure 2-1 and Tables 2-1 and 2-2 have been adopted from the EPA report with minor changes.

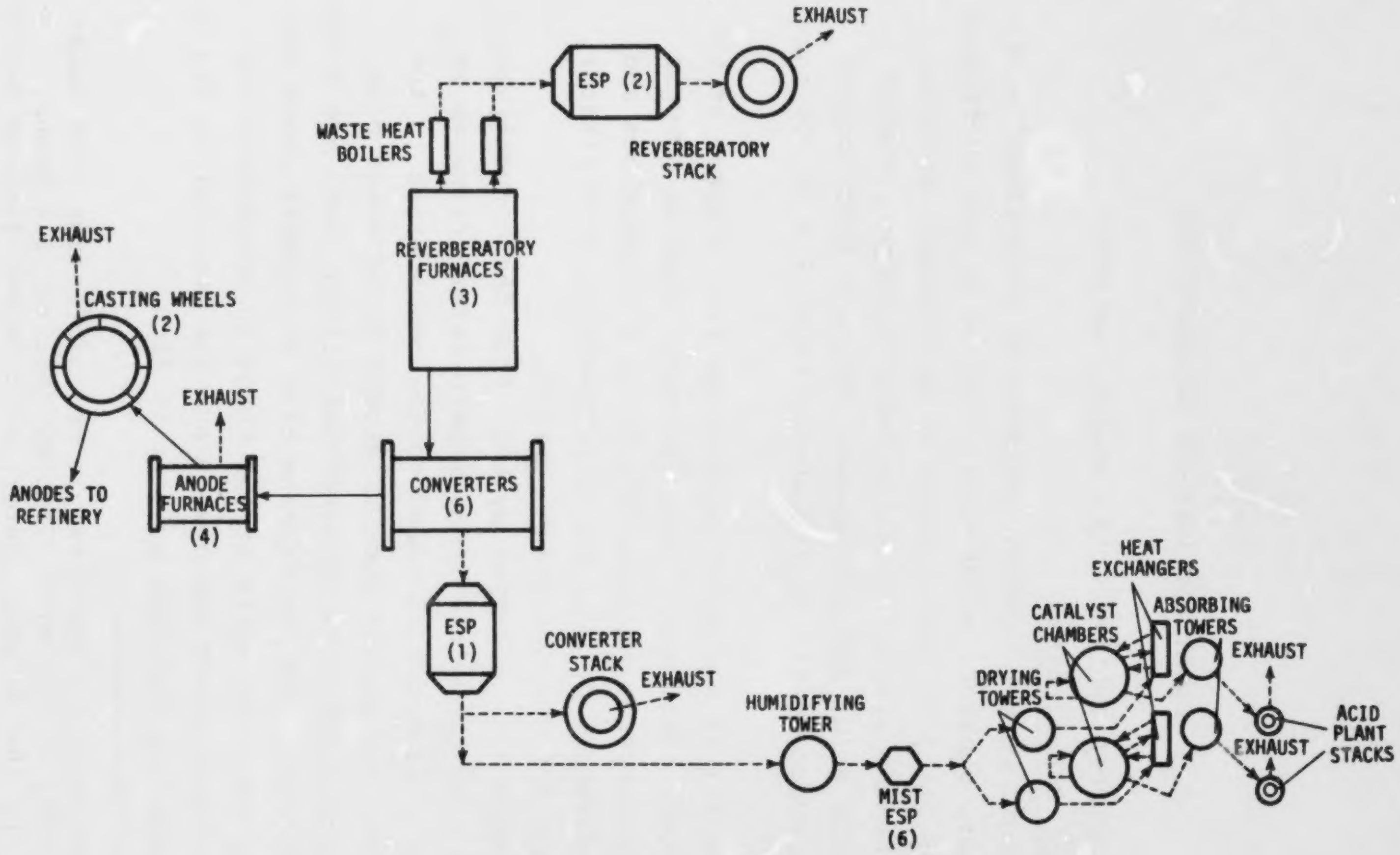
EXHAUST
ESP (2)
WASTE HEAT BOILERS
REVERBERATORY STACK
EXHAUST
CASTING WHEELS (2)
REVERBERATORY FURNACES (3)
EXHAUST
ANODES TO REFINERY
ANODE FURNACES (4)
CONVERTERS (6)
HEAT EXCHANGERS
CATALYST CHAMBERS
ABSORBING TOWERS
ESP (1)
CONVERTER STACK
EXHAUST
DRYING TOWERS
EXHAUST
HUMIDIFYING TOWER
ACID PLANT STACKS
EXHAUST
MIST ESP (6)

Figure 2-1. Simplified process flow diagram of Magma Copper Company plant, San Manuel, Arizona.

Table 2-1. SMELTER PROCESS EQUIPMENT AND OPERATING DATA FOR MAGMA COPPER COMPANY, SAN MANUEL, ARIZONA

Parameter	Reverberatory furnaces[a]		Converters[b]	
Feed rate:	metric tons/day	tons/day	metric tons/day	tons/day
Concentrates	2004	2208		
Flux	202	222	251	276
Converter slag	1089	1200		
Matte	-	-		
Flue dust	NA	NA		
Total	3295	3630	1504	1656
Size of unit:	meters	feet	meters	feet
Width	c	c		
Length	31	102	10.7	35
Height	3.4	11		
Diameter			d	d
Gas volume generated at Std. conditions[f]:	m^3/min 8200	cfm 289,500	m^3/min[e] 3 at 690 3 at 1070	cfm[e] 3 at 24,500 3 at 37,700
Exit gas temperature:	260°C	500°F	704°C	1300°F[g]

---

[a] Three units operating 720 to 744 hours per month.

[b] Six units operating an estimated 432 hours (60% of 720) per month per converter.

[c] The respective widths of each of the three reverberatory furnaces are 9.8 m (32 ft), 10.4 m (34 ft), and 11.0 m (36 ft).

[d] Three of the six converters are 4 m (13 ft) each in diameter, and the remaining are 4.6 m (15 ft) each.

[e] Undiluted maximum gas flow per converter. Units do not usually operate simultaneously under peak flow conditions.

[f] Standard conditions are 760 mm Hg (14.7 psia) and 21°C (70°F).

[g] Maximum temperature reached during final copper blow.

Table 2-2. REVERBERATORY FURNACE AIR POLLUTION CONTROL EQUIPMENT AND OPERATING DATA, MAGMA COPPER COMPANY - SAN MANUEL, ARIZONA

Control device	Manufacturer	Date of installation/ modification	No. of units and stages	Gas flow rate,[a]		Operating temp.		Pressure drop		Collection area		Velocity		Reten-tion time
				m^3/min	scfm	°C	°F	cm[b]	in[b]	m^2	ft^2	m/sec	ft/sec	sec
ESP	Research-Cottrell	1975	1-4[c] stages	2730	96,500	260 to 354	500 to 670	0.9	0.35	6780	72,900	1.1	3.57	7.56
			1-6[d] stages	5470	193,000					13,540	145,800			

---

[a] Estimated gas flow through individual units (Basis for estimate unknown).

[b] Water column.

[c] West unit.

[d] East unit.

On the inside, the three reverberatory furnaces are 31 m (102 ft) long and 3.5 m (11 ft) high. The widths are 10, 10.5, and 11 m (32, 34, and 36 ft) for Furnaces 1, 2, and 3, respectively. Although normally fired with natural gas, fuel oil is used when gas delivery is interrupted. Work is currently underway to convert to coal firing.

The reverberatory furnace walls are made of basic brick. At the slag line, 76 copper water jackets 0.6 m (2 ft) high by 1.5 m (5 ft) long nearly surround three sides of the furnaces. The suspended-arch roof also is constructed of basic brick. The walls and arch are maintained by replacing brick; no hot patching is used.

Although the depth of molten material actually varies among the three furnaces, normal slag depth is approximately 102 cm (40 in.) and normal matte depth is approximately 38 cm (15 in.). Slag is tapped near one end of each furnace and flows through a launder into slag pots, which are hauled by rail to the slag dump. Matte is tapped nearer the center of the furnaces, depending on converter or reverberatory furnace conditions, and carried in a launder one floor below the furnaces. The matte drops by gravity off the launder into ladles resting on a pallet, which is moved into the converter aisle by an electric winch and cable unit.

The matte ladles are picked up by an overhead crane and charged to one of six Peirce-Smith converters. Converters 1, 2, and 3 are 4 by 11 m (13 by 35 ft), and Converters 4, 5, and 6 are 4.5 by 11 m (15 by 35 ft). An initial charge to a converter normally consists of two to four ladles of matte. Air is blown through tuyeres into the charge, flux is added, and the slag produced is skimmed into a ladle. The slag is then returned by overhead crane to one of the reverberatory furnaces. Additional matte is added to the converter until a total of approximately 65 metric tons (70 tons) of blister copper is produced.

The blister copper is poured into ladles, then carried by overhead crane to one of four anode furnaces, two of which are 4 by 9 m (13 by 30 ft), and the other two, 4 by 11 m (13 by 35 ft). Additional air is blown through tuyeres into the charge to assure complete oxidation. Reformed natural gas or propane is then introduced through the tuyeres for final copper reduction. The refined copper is cast into anodes of approximately 360 kg (800 lb) on either of two casting wheels. The anodes are cooled, inspected, and transferred to the electrolytic refinery.

2.1.2 Emissions Sources and Reverberatory Furnace Control Equipment

The primary particulate sources at the smelter are the reverberatory furnaces and the converters, the majority of whose exhaust gases are treated by control systems. Fugitive emissions from feeding concentrates, skimming converter slag, or returning converter slag, however, are neither collected nor treated; they are exhausted directly to the atmosphere. The reverberatory furnace matte and slag tap areas are hooded, and collected gases containing particulate matter are exhausted untreated directly to individual stacks above the building. Converter "smoke" not collected by the primary hood system is likewise released directly to the atmosphere. The anode furnaces also emit some untreated particulate matter directly to the atmosphere above the converter aisle.

The principal reverberatory furnace exhaust gases pass through a pair of waste-heat boilers following each furnace. The partially cooled gases are then combined into a common duct before entering the plenum chamber of two parallel ESP units. The unit called the "east ESP" is designed to handle about two-thirds of the gas volume, and the other called the "west ESP" is designed to handle one-third. Shortly after installation, however, the perforation plates between the plenum and the ESP units were removed because of excessive plugging. Assuming that gas flow distribution is actually as designed, the east ESP handles 5470 m^3/min (193,000 scfm), and the west ESP handles 2730 m^3/min (96,500 scfm), as shown in Table 2-2. The east ESP consists of six stages with a total collection area of 13,540 m^2 (145,800 ft^2), whereas the west ESP consists of four stages with a total collection area of 6780 m^2 (72,900 ft^2). Average gas velocity is 1.1 m (3.6 ft)/sec and retention time is less than 8 sec. The pressure drop across each ESP is 0.8 cm (0.35 in.) H_2O maximum. The exit gas stream is exhausted to a 157-m (515-ft) stack for discharge to the atmosphere.

2.1.3 Chronology of Enforcement Actions for Magma Copper Company at San Manuel, Arizona

Table 2-3 presents a chronology of enforcement actions by the EPA.

2.2 PHELPS DODGE COPPER SMELTER - AJO, ARIZONA*

2.2.1 Plant Description

The New Cornelia Branch of the Phelps Dodge Corporation operates a mine, concentrator, and smelter at Ajo, Arizona, for the production of anode copper from a chalcopyrite (copper-iron sulfide) concentrate. During 1975, production averaged 165 metric tons (185 tons)/day.

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* This discussion is based mainly on information from State Implementation Plan Inspection of Phelps Dodge Corporation, New Cornelia Branch Smelter, Ajo, Arizona, by the Environmental Protection Agency, May 1976. Figure 2-2 and Tables 2-3 and 2-4 have been adapted from the EPA report with minor changes.

Table 2-3. CHRONOLOGY OF ENFORCEMENT ACTIONS - MAGMA COPPER COMPANY, SAN MANUEL, ARIZONA[a]

Date	Action
May 14, 1973	EPA promulgated process weight regulation 40 CFR 52·126(b).
July 13, 1973	EPA notified company by letter of process weight regulation requirements.
September - November, 1973	Company submitted proposed compliance schedules.
April 3, 1974	EPA held public hearing in Phoenix on proposed compliance schedule.
December 12, 1974	EPA approved compliance schedules for converters and reverberatory furnaces.
January 6, 1975	Magma notified EPA of violations of both compliance schedules.
March 5, 1975	EPA issued consent order to company.
June 11, 1975	Company submitted test results of converter-side acid plant. Compliance demonstrated.
October, 1975	Company conducted tests in reverberatory furnace stack, which showed emissions to exceed allowable by a factor of 20 to 30.
November 26, 1975	Company filed Petition for Reconsideration and Revision of process weight regulation (EPA).
December 31, 1975	Letter from P. DeFalco, Administrator of Region IX, EPA, to H.A. Twitty, Attorney for Magma Copper Company, stated that Region IX would review the process weight regulation.
January 30, 1976	National Enforcement Investigations Center (NEIC), Office of Air Quality Planning and Standards (OAQPS), and Region IX EPA personnel visited the smelter.
May 12-22, 1976	Smelter was tested by EPA and NEIC team.

[a] Provided by Larry Bowerman of EPA Region IX.

(Continued)

Table 2-3. (continued) CHRONOLOGY OF ENFORCEMENT ACTIONS - MAGMA COPPER COMPANY, SAN MANUEL, ARIZONA

Date	Action
March 28, 1977	R.L. O'Connell, Director of Enforcement Division, EPA, sent letter pursuant to Section 114 to Magma Copper Company, requesting further information about particulate removal systems installed for reverberatory furnace gases.
May 18, 1977	Magma Copper Company responded to EPA letter of March 28, 1977.

Figure 2-2 is a simplified process flow diagram for this smelter. Table 2-4 lists the major smelter process equipment and operating data, and Table 2-5 lists the air pollution control equipment and operating data. Concentrate is delivered by a belt conveyor, 61-cm (24-in.) wide, from the New Cornelia concentrator to the smelter, where it is dried in a rotary dryer fired either by natural gas (when available) or by diesel fuel.

As it enters the smelter building, the belt-delivered concentrate is mixed with limestone flux in predetermined proportions, then bedded. When available, dust from the collectors is also added to the concentrate and crushed limestone. Concentrates from other copper concentrators (notably Tyrone, Bagdad, and Bruce) and copper precipitates from the Phelps Dodge Tyrone operation are also bedded as available.

The various materials to be smelted are put into 9-metric-ton (10-ton) "cans," which are large cylindrical containers used to charge the reverberatory furnace. The filled can is moved by an overhead crane either to storage or to one of six furnace-charging stations for a single reverberatory furnace.

The reverberatory furnace, which is 30 m (100 ft) long and 9 m (30 ft) wide on the inside, is mounted on a heavily reinforced concrete foundation. Although the furnace normally fires natural gas, it can run on fuel oil if gas delivery is interrupted.

Reverberatory furnace walls are made of silica brick, with an interior protective surface of basic brick and, in the area of the crucible, a mixture of tamped periclase and firebrick. The walls also include copper water jackets, 51 cm (20 in.) high, immediately above the crucible. The

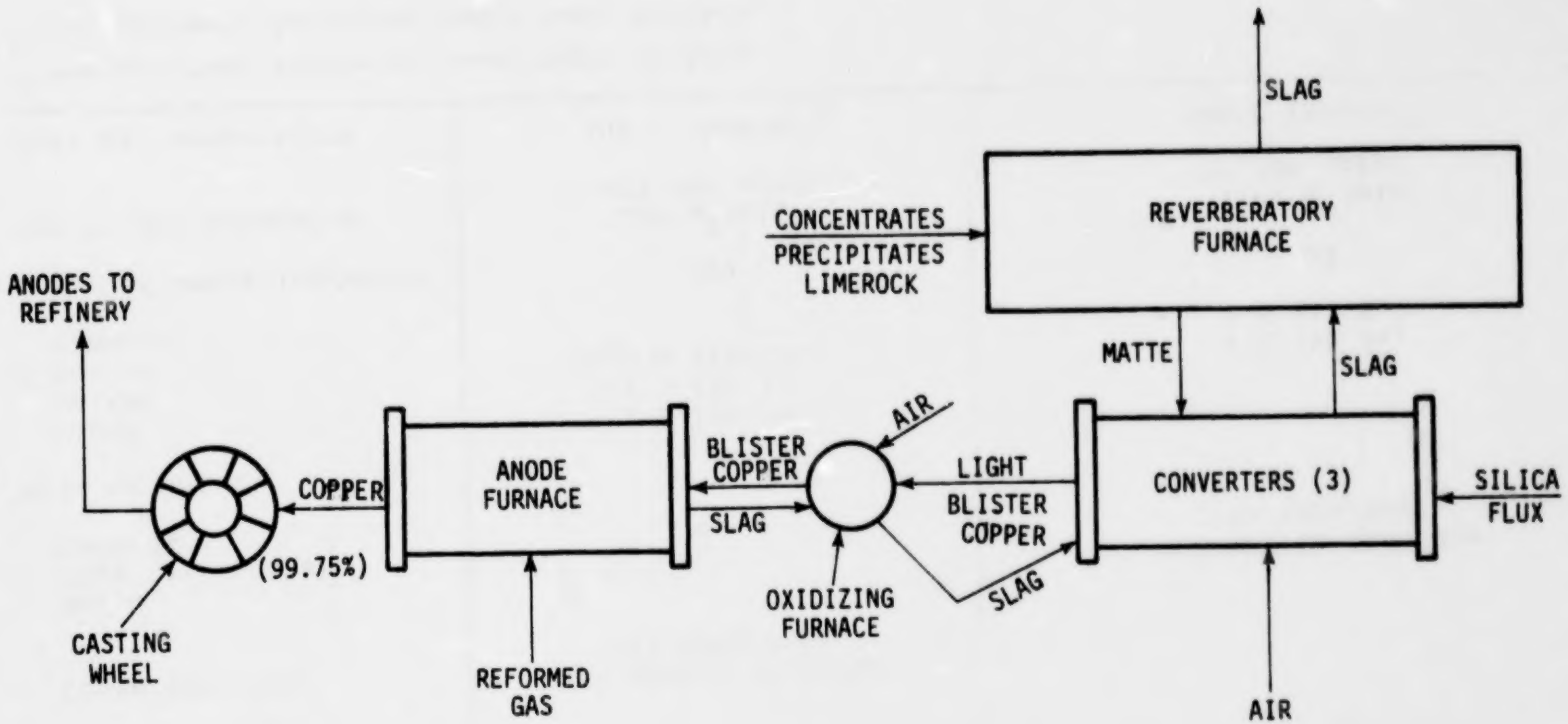
SLAG
CONCENTRATES
PRECIPITATES
LIMEROCK
REVERBERATORY FURNACE
MATTE
SLAG
ANODES TO REFINERY
AIR
BLISTER COPPER
SLAG
LIGHT BLISTER COPPER
SLAG
COPPER
(99.75%)
ANODE FURNACE
CONVERTERS (3)
SILICA FLUX
OXIDIZING FURNACE
CASTING WHEEL
REFORMED GAS
AIR

Figure 2-2. Process flow diagram for Phelps Dodge Corporation plant, Ajo, Arizona.

Table 2-4. SMELTER PROCESS EQUIPMENT AND OPERATING DATA - PHELPS DODGE CORPORATION, AJO, ARIZONA

Parameter	Reverberatory furnace	Converters
Number of units	1	3
Feed rate:		
Concentrates Precipitates Limestone Reverts	613 metric tons/day (676 tons/day)	
Converter slag	431 metric tons/day (475 tons/day)	
Matte Flux (siliceous) Reverts		725 metric tons/day (799 tons/day)
Size of unit:		
Width	9.2 m (30 ft)	
Height	3.4 m (11 ft)	
Length	30.5 m (100 ft)	9 m (30 ft)
Diameter		4 m (13 ft)
Hours of operation/month	624	522
Gas volume generated	220 m^3/min (77,900 scfm)	1100 m^3/min (39,500 scfm)
Exit gas temperature	309°C (588°F)[a]	340°C (650°F)[b]

[a] Per recorder following waste-heat boilers.

[b] Per estimate following waste-heat boilers.

Table 2-5. REVERBERATORY FURNACE AIR POLLUTION CONTROL EQUIPMENT AND OPERATING DATA, PHELPS DODGE CORPATION - AJO, ARIZONA

Control device[a]	Manufacturer	Date of installation/ modification	No. of units and stages	Gas flow rate,		Operating temp.,		Pressure drop, H_2O		Collection area,		Velocity,		Retention time, sec
				m^3/min	scfm	°C	°F	cm	in.	m^2	ft^2	m/sec	ft/sec	
ESP	Western Precipitator (Type R)	8/73	2 (with 2 stages each)	2200 each unit	77,900	309	588	1.3	0.5	1927	20,738	0.9	3.0	6.6
						Inlet								
						230	450							
						Outlet								
Scrubbers[b,c]		1/75	1	700 to 1200	25,000 to 43,000	200 to 290	400 to 550	3.8	1.5	NA[d]		NA		NA
						Inlet								
						52 to 66	125 to 150							
						Outlet								
Liquid SO_2 plant[e]		7/74	1	1100	38,500	32	90	Unknown		NA		NA		NA

[a] Scrubbers and liquid SO_2 plant are not operating at present.

[b] Only includes humidifying tower, not the cooling tower, preceding liquid SO_2 plant.

[c] Design and construction by Stearns-Roger in collaboration with Monsanto; no special type or model number designated.

[d] NA - Not applicable.

[e] DMA process developed by ASARCO; engineering and construction by Stearns-Roger.

reverberatory furnace roof is a sprung arch constructed of silica brick. The furnace walls and arch are maintained by hot patching with silica slurry.

The following procedure is followed in charging the reverberatory furnace. A container of concentrate is positioned at one of the six charging stations. Then the bottom gates of the container are opened, and the charge falls into a small feed hopper of the charging machine (referred to as a "slinger") immediately below. (The slinger is a short, high-speed, portable belt conveyor pivoted on a vertical shaft to permit lateral swinging.) The concentrate falls from the feed hopper onto the rapidly moving belt and is discharged into the furnace as it moves over the belt pulley. The usual charge is 1.8 to 3.6 metric tons (2 to 4 tons), fed at an average rate of approximately 0.9 metric ton (1 ton)/min.

Normal depth of the molten material in the furnace is approximately 120 cm (46 in.), of which 66 to 76 cm (26 to 30 in.) is matte. Slag is tapped through the side wall and flows through a launder into slag pots, which are hauled by rail to the slag dump. Matte is tapped, as required by converter or reverberatory furnace conditions, into ladles resting on electric-powered trucks which can be moved into the converter aisle.

The matte ladles are picked up by overhead crane and charged to one of three Peirce-Smith converters measuring 4 by 9 m (13 by 30 ft). The initial charge to a converter normally consists of four ladles of matte weighing 14 metric tons (16 tons) each. Air is blown through tuyeres into the charge, flux is added, and the slag produced is skimmed into a ladle. The converter slag is then returned to the reverberatory furnace by the overhead crane. Additional matte is added to the converter to produce a total of approximately 50 metric tons (55 tons) of light blister copper.

The light blister copper is poured into ladles and carried by overhead crane to a Great Falls converter, 4 m (12 ft) in diameter, that has been modified to serve as a holding furnace for final oxidation. The charge in the oxidizing furnace is air-blown through tuyeres to complete sulfur removal. Final oxidation in a holding furnace is considered necessary to prolong brick life in the converters and anode furnaces.

Following completion of oxidation in the modified Great Falls converter, the copper is transferred to the anode furnace, which is 9 m (30 ft) long and 4 m (13 ft) in diameter. Reformed natural gas (cracked methane) is introduced through tuyeres for final copper reduction. The anode-grade molten copper is cast into 330-kg (720-lb) anodes on a 22-mold casting wheel. Anodes are cooled, inspected, and loaded on flat rail cars for shipment to the Phelps Dodge refinery in El Paso, Texas.

2.2.2 Emission Sources and Reverberatory Furnace Control Equipment

The primary particulate sources at the Ajo smelter are the reverberatory furnace and the converters. Although most of the exhaust gas produced by these sources is treated before exhausting to the atmosphere, fugitive emissions escape from feeding concentrates, skimming converter slag, or returning converter slag. Though the reverberatory furnace matte and slag tap areas are hooded, the collected particulate-laden gases are simply exhausted to the smelter main stack. Similarly, converter "smoke" not captured by the primary hood system is taken by a secondary hood system directly to the smelter main stack. The oxidizing and anode furnaces also exhaust particulate-laden emissions directly to the atmosphere above the converter aisle.

The principal reverberatory furnace exhaust gases pass through a pair of waste-heat boilers before entering a common plenum chamber for the two independent and parallel ESP units. The two units were designed to handle 4200 m^3/min (150,000 acfm) total volume at 315°C (600°F) and 95 kPa (13.8 psia), but typical gas flow is 4640 m^3/min (164,000 acfm) at about 309°C (588°F). Each ESP unit consists of two stages with a total collection area of 1930 m^2 (20,700 ft^2). Average gas velocity is 0.9 m/sec (3 ft/sec), and treatment retention time is less than 7 sec. The maximum pressure drop across a unit is 1.3 cm (0.5 in.) H_2O.

Originally gas cleaning equipment was installed to direct about 50 percent [1100 m^3/min (38,500 scfm)] of the ESP exit gas stream through a DMA (dimethylaniline) sulfur dioxide (SO_2) absorption plant, and the other half was exhausted to the 110-m (360-ft) main stack of the smelter. The duct work for directing ESP exit gas to the the DMA absorption plant is now blanked off, and the entire gas stream from the ESP outlet is discharged through the main stack to the atmosphere.

In the DMA plant, which is now inoperative, the gas stream first enters a humidifying tower for evaporative cooling by a weak acid solution and removal of some of the residual particulate matter. The gases then enter a cooling tower, where a weak acid solution percolates down through packing, which cools the ascending gases and removes more of the remaining particulate matter. After passage of the exhaust gases through a mist precipitator for removal of acid mist and remaining dust particles, the cleaned gas stream enters the DMA absorption tower for SO_2 removal. The acid scrubbing section of the DMA absorption tower removes

Table 2-6. CHRONOLOGY OF ENFORCEMENT ACTIONS -

PHELPS DODGE COPPER COMPANY, AJO, ARIZONA[a]

Date	Action
May 14, 1973	EPA promulgated process weight regulation 40 CFR 52·126(b).
July 13, 1973	EPA notified company by letter of process weight regulation requirement.
January 23, 1974	Company notified EPA that it considers itself to be in compliance with process weight regulation. No stack test results submitted.
March 24, 1975	EPA sent company a Section 114 letter requiring stack test results be submitted to demonstrate compliance.
May 5 and 6, 1975	Company submitted test results. The results showed emissions that were about three times allowable emissions.
June 30, 1975	EPA issued a Notice of Violation.
August 28, 1975	A conference was held between EPA, Phelps Dodge, and Arizona State Agency.
September, 1975	Company conducted new emission tests, which showed the emissions were 3.3 times the allowable emissions.
October 1, 1975	Company filed Petition for Review of process weight regulation (Ninth Circuit).
October 6, 1975	Company filed application for stay pending EPA review.

[a] Provided by Larry Bowerman of EPA Region IX.

(Continued)

Table 2-6 (continued).

Date	Action
October 17, 1975	Company submitted Petition for Reconsideration and Revision to EPA.
November 5, 1975	Letter from Russell E. Train (Administrator, EPA) to Senator Goldwater stated that EPA had agreed to review any new information submitted by Phelps Dodge involving the process weight regulation.
November 28, 1975	Letter from P. Defalco, Administrator of EPA Region IX to John F. Boland, Jr., advised that Region IX would review the process weight regulation and that enforcement action was stayed.
January 15, 1976	National Enforcement Investigations Center (NEIC), Office of Air Quality Planning and Standards (OAQPS), and Region IX EPA personnel visited the smelter.
April 7, 1976	Letter from R.L. O'Connell, Director of Enforcement Division, EPA, to D.H. Orr, Manager, New Cornelia Branch, Phelps Dodge Corporation, indicated installation of sampling facilities was required pursuant to Section 114.
July 5-16, 1976	Extensive testing was conducted by EPA contractors (Southern Research Institute and Radian) at the reverberatory furnace electrostatic precipitator.
July 15-30, 1976	Extensive testing was conducted by EPA contractor (Acurex Corporation/Aerotherm Division) at the reverberatory furnace ESP Outlet, and acid plant outlet, and main stack.
March 28, 1977	Letter pursuant to Section 114 from O'Connell, Director of Enforcement Division, EPA, to Phelps Dodge requested further information about installation of particulate-removal systems reverberatory furnace gases.
May 9, 1977	Phelps Dodge responded to EPA letter of March 28, 1977.

3.0 EMISSION TEST DATA

3.1 ANALYSIS OF ELECTROSTATIC PRECIPITATOR PERFORMANCE DATA ON REVERBERATORY FURNACE AT MAGMA COPPER COMPANY, SAN MANUEL, ARIZONA

At the request of EPA Region IX, the National Enforcement Investigations Center (NEIC) in Denver conducted emission tests from May 14 to 18, 1976, on the reverberatory furnace stack of the Magma Copper Company in San Manuel, Arizona, to determine compliance with the process weight regulations, and again from May 19 to 21, 1976, to evaluate the effect of temperature on the formation of particulate. Before these tests, Magma Copper had also conducted compliance tests on the furnace stack (July 30 and 31, 1975).

Design parameters of reverberatory furnace ESP's, actual performance data, and compliance test data (by both NEIC and Magma Copper) are presented in Table 3-1.

At the San Manuel smelter, reverberatory furnace exhaust gases pass through a pair of waste-heat boilers following each furnace. The partially cooled gases are then combined in a common duct before entering the plenum chambers of the two separately housed units of the ESP.

The two-unit ESP was manufactured by Research Cottrell and installed in 1975. It is designed for 98 percent particulate removal, based on the ASME test methods. Compliance testing and results on the ESP are discussed in the following paragraphs.

NEIC Compliance Test Conducted May 14-18

Using EPA Method 5, NEIC conducted sampling tests on the reverberatory furnace stack as a part of compliance

Table 3-1. SUMMARY OF PARTICULATE EMISSION DATA FOR ELECTROSTATIC PRECIPITATOR ON REVERBERATORY FURNACE-MAGMA COPPER COMPANY, SAN MANUEL, ARIZONA

Item	Design (1)[a]	Actual (1)	Compliance tests conducted by company, Oct. 30-31, 1975 (2)	EPA compliance tests by NEIC May 14 to 18, 1976 (3)
ESP manufacturer	Research Cottrell			
ESP inlet conditions				
Volume flow at continuous				
rating, actual: m^3/min	15,800 (calc.)	15,800 (calc.)		
(acfm)	(560,000)	(560,000)		
standard: m^3/min	8040	8040		
(scfm)	(284,000)	(284,000)		
Temperature: °C	260-354	260-354		
(°F)	(500-670)	(500-670)		
Gas dust loadings:				
by instack filter,				
g/m^3	1.91	1.91		
(gr/scf)	(0.836)	(0.836)		
kg/hr	922 (calc.)	922 (calc.)		
(lb/hr)	(2035, calc.)	2035, calc.)		
by instack/outstack filter,				
g/m^3				
(gr/scf)				
kg/hr				
(lb/hr)				
by EPA Test Method 5,				
g/m^3				
(gr/scf)				
kg/hr				
(lb/hr)				
ESP outlet conditions				
Volume flow at continuous				
rating, actual: m^3/min			18,280 (calc.)	18,160 (calc.)
(acfm)			(645,500, calc.)	(641, 200, calc.)
standard: m^3/min			9378[b]	9316[c]
(scfm)			(331,200)[b]	(329,000)[c]
Temperature °C			300	300
(°F)			(573)	(573)

(Continued)

Table 3-1 (continued).

Item	Design (1)[a]	Actual (1)	Compliance tests conducted by company, Oct. 30-31, 1975 (2)	EPA compliance tests by NEIC May 14 to 18, 1976 (3)
by instack filter,				
g/m^3	0.02869			
(gr/scf)	(0.01254)			
kg/hr	14.04 (calc.)			
(lb/hr)	(30.53, calc.)			
by EPA Test Method 5,				
g/m^3			0.275 to 0.898[d]	1.76[e]
(gr/scf)			(0.1201 to 0.3924)	(0.77)
kg/hr			158 to 486	990[f]
(lb/hr)			(349 to 1071)	(2180)
ESP control efficiency, %	98.0[g]			
Allowable emissions,				
g/m^3				0.032 (calc.)
(gr/scf)				(0.014)
kg/hr				18
(lb/hr)				(39.7)
At ESP outlet				
SO_2 emissions, ppm				5400[h]
kg/hr				8100
(lb/hr)				(17,820)
SO_3 emissions, ppm				15.9[i]
kg/hr				30
(lb/hr)				(66.2)
Moisture content, volume percent				8.7
CO_2 volume percent				4.03
O_2 volume percent				(14.17)
Metal analysis, kg/hr, (lb/hr)[j]				
Tin (Sn)				0.072 (0.16)
Arsenic (As)				2.34 (5.2)
Cadmium (Cd)				0.11 (0.25)
Chromium (Cr)				0.045 (0.10)
Copper (Cu)				4.32 (9.8)
Lead (Pb)				1.55 (3.4)
Mercury (Hg)				0.027 (0.06)
Molybdenum (Mo)				0.37 (0.81)
Nickel (Ni)				0.014 (0.03)
Selenium (Se)				0.59 (1.3)
Vanadium (V)				
Zinc (Zn)				2.34 (5.2)[k]

(Continued)

Table 3-1 (continued).

Footnotes

[a] Numbers in parenthesis represent corresponding reference listed.

[b] Average of four compliance test runs conducted by Magma on October 30 and 31, 1975. Included in Appendix A, Magma Petition for Revision Table 1, page 4. NEIC report.

[c] Average of three compliance tests conducted by NEIC from May 14-22, 1976. The actual flow rates were 9770, 8864, and 9298 m^3/min (345,000, 313,000, and 328,300 scfm) respectively.

[d] Actual emissions during four compliance tests conducted by Magma on October 30 and 31, 1975 were 0.75, 0.50, 0.28, and 0.90 g/m^3(0.3268, 0.2202, 0.1201, and 0.3924 gr/scf respectively. Isokinetic conditions were not met during all the tests.

[e] Average of three test runs [1.63, 1.95, and 1.63 g/m^3 (0.71, 0.85, and 0.71 gr/scf)] conducted.

[f] Actual emissions during the three tests were 948, 1111, and 907 kg/hr (2090, 2450, and 2000 lb/hr).

[g] Based on instack filter tests.

[h] Average of three test runs. Actual measurements were 4500, 6670, and 5030 ppm respectively.

[i] Average of three test runs. Acutal measurements were 12.8, 16.2, and 18.7 ppm respectively.

[j] Metals identified in particulates collected by EPA Method 5 in ESP outlet during the second compliance test run.

[k] Filter zinc results are questionable.

Reference

1) State Implementation Plan Inspection of San Manuel Division Smelter, Magma Copper Company, San Manuel, Arizona. June 1976. In: Emission Testing at the Magma Copper Company Smelter, San Manuel, Arizona, by National Enforcement Investigations Center. EPA-330/2-76-029. May 2-22, 1976.

2) Appendix A, Magma Petition for Revision In: Emission Testing at the Magma Copper Company Smelter, San Manuel, Arizona, by National Enforcement Investigations Center. EPA-330/2-76-029. May 2-22, 1976.

3) Test Results. In: Emission Testing at the Magma Copper Company Smelter, San Manuel, Arizona. bv National Enforcement Investigations Center. EPA 330/2-76-029. May 12-22, 1976.

testing at the San Manuel smelter. During the test program, NEIC also collected process input data for calculating the allowable emissions from the reverberatory furnace.

Three valid sampling runs were reported, using the four available sampling ports at the 80-m (262-ft) level of the 157-m (515-ft) stack. These test runs were performed within the isokinetic range of 90 to 110 percent. The sample volumes collected during these test runs were 1.692, 1.698, and 1.632 m^3 (59.76, 59.97, and 57.63 ft^3) with process inputs of 159, 157, and 169 metric tons/hr (176, 173, and 186 tons/hr) respectively. The sample from Run 2 was also analyzed for its metallic content.

Table 3-2 presents particulate emissions computed from the test data, and allowable emissions calculated from process weight input data.

Table 3-2. PARTICULATE EMISSION DATA

Run	Actual particulate emissions		Allowable particulate emissions	
	kg/sec	lb/hr	kg/sec	lb/hr
1	.263	2090	.005	39.6
2	.309	2450	.005	39.5
3	.252	2000	.005	39.5
Average	.275	2180	.005	39.5

Table 3-3 lists quantities of metallic elements detected in the filter catch and acetone wash of Run 2, the principal ones being copper, lead, arsenic, and zinc. The amount of arsenic caught in the impinger of the sample train was insignificant compared with that caught in the filter. During the three tests, the gas moisture contents measured 8.9, 8.3, and 8.9 volume percent respectively. Sulfur

Table 3-3. ANALYSIS OF METALLIC ELEMENTS IN GAS SAMPLE RUN 2

Element	Amount detected,[a] µg	Emission rate,	
		g/hr	lb/hr
Tin (Sn)	228	74.4	0.16
Arsenic (As)	7,200	2,375	5.2
Cadmium (Cd)	340	112	0.25
Chromium (Cr)	144	47.3	0.10
Copper (Cu)	13,500	4,453	9.8
Lead (Pb)	4,700	1,550	3.4
Mercury (Hg)	76	25.0	0.06
Molybdenum (Mo)	1,110	367	0.81
Nickel (Ni)	36	11.7	0.03
Selenium (Se)	1,790	590	1.3
Vanadium (V)[b]			
Zinc (Zn)[c]	7,200	2,375	5.2

[a] Includes both filter and acetone wash.

[b] Vanadium results below background levels observed in the blank filters.

[c] Zinc results include only acetone catch. The filter zinc results are questionable because of the high zinc levels found in the blank filters.

dioxide emissions were about eight times greater than particulate emissions. Table 3-4 gives the amounts of SO_2 and SO_3 in the sample tests as calculated by NEIC.

Table 3-4. SULFUR DIOXIDE EMISSIONS

Run	SO_2 conc. ppm	SO_2 emission lb/hr	SO_2 emission kg/sec	SO_3 conc. ppm	SO_3 emission lb/hr	SO_3 emission kg/sec
1	4500	15,680	1.97	12.8	56.1	0.007
2	6670	21,100	2.66	16.2	64.5	0.008
3	5030	16,700	2.10	18.7	78.0	0.010
Average	5400	17,820	2.25	15.9	66.2	0.008

The NEIC believes the reported values of sulfur dioxide emissions are conservative, because the sulfur dioxide gas dissolved in the first impinger (water) of the sample train would not be detected by the sulfate analytical method (i.e., SO_2 caught in Impinger 1 is not included in the SO_2 emission results). No sulfate was found in the filter or acetone wash catches during the testing.

Based on the test results, NEIC concluded that the high particulate concentration in the reverberatory furnace flue gas indicates the ESP is not providing effective control. According to the Magma Copper data, an average of 114 metric tons (125 tons) of fines per day is recycled from the reverberatory and converter ESP's to the reverberatory furnace. This amount is substantially less than the 218 metric tons (240 tons) per day that would be collected by the reverberatory furnace ESP if it were operating at least at a 90 percent efficiency level. Recycle weights were not available to NEIC for the specific times during which tests were conducted.

The average stack gas flow rate during the tests measured approximately 9313 m^3/min (328,900 scfm) and the stack temperature averaged 300°C (573°F).

NEIC Ancillary Test Data

NEIC conducted additional testing on the reverberatory furnace stack on May 19 and 21, 1976, to evaluate the effect of temperature on particulate formation. Five tests were conducted using two sampling trains simultaneously in two ports, one equipped with an instack filter in combination with an outstack filter and the other with a standard Method 5 outstack filter. The sampling probes were about 5 ft apart. Particulate was measured using the instack-outstack filter train in the south port for the first three readings and in the north port for the other two readings, while the outstack filter train was kept in the west port throughout the five runs. Based on these ancillary tests, NEIC reached the following conclusions: a) particulate is apparently formed as the reverberatory gases are cooled during sampling from an average stack temperature of 274°C (526°F) to a filter temperature of 120°C (250°F); (b) particulate sulfate appears to be formed as the reverberatory gases pass through the instack filter; and (c) simultaneous samples should be obtained from sampling points as close to each other as possible without causing aerodynamic disturbances, in order to define the effect of temperature on particulate collection.

Sample times for the five runs varied from 10 to 58 minutes and sample volumes from 0.169 to 1.028 m^3 (6 to 36 scf). The stack gas temperature measured during sampling averaged 274°C (526°F) and ranged from 223° to 306°C (434° to 583°F), and the average gas moisture content was 8.8 volume percent with a 3.1 to 13.1 percent variation. All measurements were made under isokinetic conditions.

Consistently less particulate was collected on the outstack filter train during the first four runs than on the outstack filter of the instack/outstack filter train.

During the five runs, the particulate collected by the outstack filter train was 17.44, 61.57, 51.8, 52.34, and 139.29 percent of that collected on the instack/outstack filter train. The particulate collected on the instack filter of the instack/outstack train ranged from 1.4 to 49 percent. [In all cases, the particulate collected on the instack filter at approximately 282°C (540°F) ranged from 2 to 44 percent of that collected by the outstack filter of the other train.]

After further study of the tests for sulfate formation, NEIC made the following observations: analyses performed on the outstack filter of the instack/outstack train indicate that from 19 to 57 percent of the particulate collected was a sulfate material. No sulfates were found in the instack filter nor on the filters for Runs 3, 4, and 5 of the outstack train. The data do not explain why sulfates were present in the front half of Runs 1 and 2 of the outstack train, but not in Runs 3, 4, and 5. Analyses of Impingers 1, 2, and 3 indicated SO_3 concentrations of 31 to 93 ppm and SO_2 concentrations of 2600 to 5000 ppm by volume. These amounts show higher SO_3 concentrations and lower SO_2 concentrations than those observed during the compliance testing. The arsenic content of Impinger 4 was insignificant (i.e., <0.01 wt. %) when compared to the arsenic content of the filter. (NEIC did not give the arsenic content of the filter.)

Company-Conducted Compliance Tests on October 30 and 31, 1975

Since isokinetic conditions were not met during the four company-conducted sampling tests, the results cannot be considered valid. Even these test results, however, show that actual particulate emissions far exceed the allowable limits.

3.2 ANALYSIS OF ELECTROSTATIC PRECIPITATOR PERFORMANCE DATA ON REVERBERATORY FURNACE AT PHELPS DODGE CORPORATION, AJO, ARIZONA

Since 1975, many tests have been conducted to determine emission characteristics and control system performance of the reverberatory furnace at the Phelps Dodge Corporation smelter at Ajo, Arizona. Basic design parameters of the ESP, actual data reported by Phelps Dodge, and data from numerous field tests by Radian Corporation, Southern Research Institute, and Aerotherm Corporation are summarized in Table 3-5.

After reverberatory furnace gases pass through the waste-heat boilers, they are treated in an ESP at a temperature of approximately 315°C (600°F) and vented to the atmosphere through the stack.

The ESP, manufactured by the Western Precipitation Division of Joy Manufacturing Company, was installed in August 1973. Design performance of the system was based on measuring particulate at a system temperature of 315°C (600°F) by the ASME test method. The system design does not comply with EPA process weight regulations, which call for ESP outlet particulates to be measured by EPA Method 5. This method measures the particulate collected from the stream at approximately 120°C (250°F).

Detailed analyses of various tests and their data are presented in the following sections.

Radian Corporation Test Results - Radian Corporation tested particulate emissions from the reverberatory furnace ESP at the Phelps Dodge Ajo facility from June 7 to 16, 1976, to evaluate the performance of the ESP. Table 3-6 summarizes Radian's sampling program.

Radian reached the following conclusions as the result of these tests:

Table 3-5. SUMMARY OF PARTICULATE EMISSION DATA FOR ELECTROSTATIC PRECIPITATOR IN REVERBERATORY FURNACE - PHELPS DODGE COPPER SMELTER, AJO, ARIZONA

Item	Design (1)[a]	Actual (1)	Radian test results July 6-16, 1976 (2)	SRI test results July 9-10, 1976 (3)	Aerotherm test results July 15-30, 1976 (4)
ESP manufacturer	Joy Western				
ESP inlet conditions					
Velocity, m/sec			16.76 to 17.37[b]		
(fps)			(55 to 57)		
Volume flow at continuous rating, actual: m^3/min	4248[c]	4644	4531[d]		
(acfm)	(150,000)	(164,000)	(160,000)		
standard: m^3/min	(2124 calc.)	(2560 avg. calc.)	2197 (calc.)		
(scfm)	(75,000 calc.)	(90,500 avg. calc.)	(77,580 calc.)		
Temperature, °C	315 (max.)	232 to 288	334		
(°F)	(600)	(450 to 550)	(633)		
Gas dust loadings: by instack filter, g/m^3	5.15 (max.)[e]	1.35 (calc.)	avg. 1.37 (0.39 to 3.5)[f]		
(gr/scf)	(2.25)	(0.592)	(avg. 0.6, range from 0.17 to 1.55)		
kg/hr	655 (calc. max.)	191[e]	avg. 184 (calc.)[g]		
(lbs/hr)	(1446.43)	(421)	(avg. 402 calc.)		
by instack/outstack filter, g/m^3			3.57 to 5.65[h]		
(gr/scf)			(1.56 to 2.47)		
kg/hr			468 to 756 (calc.)		
(lbs/hr)			(1041 to 1648)		
by EPA Test Method 5, g/m^3					
(gr/scf)					
kg/hr					
(lbs/hr)					
standard m^3/min			2630 (calc.)		
(scfm)			92,840		
ESP outlet conditions					
Velocity, m/sec			34.7		23.5
(fps)			(114)		(77.17)

(Continued)

Table 3-5 (continued).

Item	Design (1)	Actual (1)	Radian test results July 6/16, 1976 (2)		SRI test results July 9-10, 1976 (3)	Aerotherm test results July 15-30, 1976 (4)
Volume flow at continuous rating, actual: m^3/min			5248			3290^{i}
(acfm)			(185,330)			(116,200)
standard: m^3/min			2629			1685 calc.
(scfm)			(92840)			(59500)
Temperature °C			314			288 to 316
(°F)			(598)			550 to 600
Gas dust loadings:						
by instack filter, g/m^3	0.144	0.153	0.046^{j}			0.96 (calc.)
(gr/scf)	(0.063)	(0.067)	(0.02)			(0.42)
kg/hr	18.1 (guaranteed)	21.3^{k}	6.10 (calc.)			96.5^{l}
(lb/hr)	(40)	(47)	(13.44)			(212.8)
by instack/outstack filter, g/m^3			1.92 to 3.14^{m}			1.89 (calc.)
(gr/scf)			(0.84 to 1.37)			(0.83)
kg/hr			254 to 414 (calc.)			192^{n}
(lb/hr)			(560 to 914)			(423.5)
by EPA Test Method 5, g/m^3						1.28 (calc.)
(gr/scf)						(0.56)
kg/hr						129.4^{p}
(lb/hr)						(285.4)
ESP control efficiency, %	96.83^{q}				96.7^{r}	
Allowable emissions, g/m^3						
(gr/scf)						
kg/hr						14.15
(lb/hr)						(31.2)
Dust size analysis						
at ESP inlet					< 10 µm^{s}	
at ESP outlet					< 1 µm	
Gas composition volume, %			ESP^{t} inlet	ESP^{t} outlet		ESP^{t} outlet
H_2O			13.2	12.3		12.2
O_2			10.7	9.5		13.6
CO_2			6.0	6.5		4.1
SO_2			0.33	0.56		8.1
SO_3			0.006	0.012		0.0034

Table 3-5 (continued).

Footnotes

[a] Numbers in parentheses represent corresponding references listed.

[b] Actual measurements in each of the two inlet ducts to the ESP were 16.76 and 17.37 m/sec (55 and 57 fps) respectively.

[c] At 0°C and 101.33 kPa (32°F and 14.7 psia).

[d] Average of six tests conducted July 7 through July 10, 1976. During the test runs, the volume rate varied from 4190 to 4730 m^3/min (148,000 to 167,000 acfm).

[e] 1975 tests by Engineering Testing Laboratories, using WP Method 50, hard particulates only.

[f] Result of five test runs conducted July 8 through July 10, 1976. Actual emissions varied from 0.39 to 3.6 g/m^3 (0.17 to 1.55 gr/scf).

[g] According to Radian, the outlet sampling location was much more favorable than the inlet and for this reason the gas flow rate obtained at the outlet, 2220 m^3/min (78,400 scfm), was used to calculate the flow rates of gas through the ESP. Based on this gas flow rate and average loading of 1.37 g/m^3 (0.6 gr/scf), Radian calculated a mass flow rate of 154 kg/hr (340 lb/hr).

[h] Results of two test runs performed at a single point in the one duct (two ducts lead into ESP). Test Run 1 collected 1.33 g/m^3 (0.58 gr/scf) on instack filter and 4.33 g/m^3 (1.89 gr/scf) on outstack filter, and Test Run 2 collected 0.71 g/m^3 (0.31 gr/scf) on instack filter and 2.86 g/m^3 (1.25 gr/scf) on outstack filter.

[i] Average of 11 tests conducted July 20 to 30, 1976, during which the volume flow was between 1320 and 1982 m^3/min (46,700 and 70,000 scfm).

[j] Average of five test runs conducted on July 8 to 10, 1976. The minimum and maximum dust loadings obtained during the test were 0.039 and 0.057 g/m^3 (0.017 and 0.025 gr/scf) respectively.

[k] 1975 tests by Engineering Testing Laboratories, using EPA Method 5 with sulfates deducted.

[l] Average particulates collected on instack filter during two tests conducted by using instack/outstack filters on July 29 and 30, 1976. The actual readings were 98.5 and 94.5 kg/hr (217.2 and 208.4 lb/hr).

[m] Results of three test runs. The actual readings were 2.22, 1.92, and 3.14 g/m^3 (0.97, 0.84, and 1.37 gr/scf). Amounts collected on instack filters in these three test runs were 0.06, 0.17, and 0.044 g/m^3 (0.027, 0.072, and 0.019 gr/scf respectively.

[n] Average of two test runs conducted on July 29 and 30, 1976. Actual readings were 191.9 and 192.3 kg/hr (423.0 and 423.9 lb/hr).

[p] Average of seven test runs during July 21-28, 1976. The minimum and maximum readings were 98.1 and 150.3 kg/hr (216.2 and 331.3 lb/hr) respectively.

[q] Guaranteed efficiency based on instack filter tests.

[r] Using instack filter method.

[s] Overall mass median diameter.

[t] Average of many measurements.

References

1) Appendix B. State Implementation Plan Inspection of Phelps-Lodge Corporation, Ajo, Arizona. May 1976.

2) Radian Corporation. Stack Test Results at Phelps-Dodge Corporation, Ajo, Arizona. Technical Note 200-045-57-03. January 5, 1977.

3) Southern Research Institute. Performance Evaluation of an Electrostatic Precipitator Installed on a Copper Reverberatory Furnace. Order No. CA-6-99-2980-J. January 14, 1977.

4) Acurex Corporation/Aerotherm Division. Stack Test Results at Phelps-Dodge Corporation, Ajo, Arizona, Volume I. Aerotherm Project 7211. March 1977.

Table 3-6. SUMMARY OF THE SAMPLING EFFORT (JULY 7 THROUGH JULY 16, 1976) BY RADIAN

Date	Location/stream sampled	Parameter	Technique
To evaluate reverb. ESP performance:			
July 8 to 10	ESP outlet	Grain loading	Instack filter
July 8	ESP outlet	Particle size distribution	Andersen cascade impactor (SRI)
July 8 to 10	ESP inlet	Grain loading	Instack filter
July 10	ESP inlet	Particle size distribution	Brinks cascade impactor (SRI)
July 10	ESP control room	Electrical performance	Monitor operating parameters (SRI)
To form a material balance around reverb. ESP:			
July 11	ESP outlet	Trace element flow rates	Integral WEP
July 11	ESP inlet	Trace element flow rates	Integral WEP
July 11 to 13	ESP dust	Trace element flow rates	Periodic grab sample
To form an approximate material balance around the reverb. furnace:			
July 13	ESP outlet	Trace element flow rates	Integral WEP
July 12 to 14	Reverb feed	Trace element flow rates	Compositing slinger bin catches at the end of each shift
July 11 to 13	ESP dust	Trace element flow rates	Periodic grab sample
July 12 to 14	Reberb slag	Trace element flow rates	Periodic grab sample (PD)
July 12 to 14	Matte	Trace element flow rates	Periodic grab sample (PD)
To collect particulate by particle size for trace element analysis:			
July 16	ESP outlet	Particulate by size fraction	Three outstack cyclones in series plus filter
To collect vapor phase emissions:			
July 16	ESP outlet	Trace element flow rates as vapor	Outstack filter followed by impingers
To determine amount of condensible material and SO_x emitted:			
July 15	ESP inlet	Condensed particulate (between 600-250°F) and SO_2-SO_3 concentrations	EPA Method 5 train with instack filters
July 15	ESP outlet	Condensed particulate (between 600-250°F) and SO_2-SO_3 concentrations	EPA Method 5 train with instack filters
To determine arsenic emission rates:			
July 13 to 14	ESP outlet	Arsenic emission rate	Modified EPA Method 5 train
July 13 to 14	ESP inlet	Arsenic emission rate	Modified EPA Method 5 train
July 7	ESP outlet	Velocity and temperature traverse	S-type pilot tube and thermocouples
July 7	ESP inlet	Velocity and temperature traverse	S-type pilot tube and thermocouples

1. The known major components charged to the reverberatory furnace are copper, iron, silicon, calcium, and aluminum. Titanium, potassium, magnesium, and sodium also are important.

2. Minor elements of environmental concern are arsenic, cadmium, molybdenum, lead, antimony, selenium, zinc, and fluorine. Nearly all of the arsenic, 50 percent of the selenium, and 30 percent of the fluorine, are discharged as off-gases from the reverberatory furnace. Nearly all the fluorine escapes as gas.

3. Arsenic and selenium pass through the ESP partly as vapor.

4. The waste-heat boiler seems to act as a collection chamber for arsenic and selenium compounds, which means that chemical species in the vapor phase condense on the heat exchange surfaces because of changes in gas temperature.

5. Actual gas flow rate of 4530 m^3/min (160,000 acfm) and temperature of 316°C (600°F) correspond to design parameters for the device.

6. Electrostatic precipitator inlet and outlet grain loadings determined at a duct temperature of 315°C (600°F) are 1.37 g/m^3 (0.6 gr/scf), and 0.046 g/m^3 (0.02 gr/scf) respectively.

7. When the temperature is decreased from 315 to 121°C (600 to 250°F) (as recommended by EPA), condensible materials increase to 3.66 g/m^3 (1.60 gr/scf) at the inlet and to 1.37 g/m^3 (0.60 gr/scf) at the outlet.

8. Converter off-gases and gas stream particulates not collected in the hot reverberatory furnace ESP can be almost completely removed in the gas conditioning sections of the DMA plant and the contact sulfuric acid plant. The elements removed from the gas streams will ultimately be found in the humidifier blowdown streams. (The DMA plant, which was originally installed to treat 50 percent of gases from the existing ESP, is not operated. The duct connection for these gases to the DMA plant is completely cut-off, and all treated gas is passed through the stack.)

During the testing program, Radian observed that dust loading changes from light to very heavy black and back to light, all within a few minutes, apparently as a function of furnace charging.

The gas flow rates to and from the ESP were determined from velocity measurements. Reported average velocities were 17.4 m/sec (57 ft/sec) in the east duct, 16.2 m/sec (53 ft/sec) in the west duct, and 34.7 m/sec (114 ft/sec) in the outlet duct. The respective inlet and outlet gas temperatures were 334 and 314°C (633 and 598°F). Radian reported the average gas flow rate to be 2220 m^3/min (78,400 scfm), based on a measurement at the ESP outlet (the outlet sampling location was more accessible than the inlet). Test data show that the average volume flow rate of six measurements was 2340 m^3/min (82,700 acfm) in the east inlet duct, 2190 m^3/min (77,300 acfm) in the west inlet duct, and 5247 m^3/min (185,300 acfm) in the outlet duct. These values would correspond to 2185 m^3/min (77,160 scfm) at the ESP inlet and 2629 m^3/min (92,825 scfm) at the outlet. During all measurements, except the first, outlet flow was higher than inlet, even though the outlet temperature was lower. The design flow through the ESP is 1994 standard m^3/min or 4248 m^3/min at 315°C and 92.06 kPa (70 400 scfm or 150,000 acfm at 600°F and 13.8 psia). The flow measurements, therefore, show that the actual gas treated in the ESP is about 6.7 percent higher than design, based on inlet volume flow, and about 24 percent higher based on outlet flow. This could indicate leakage of outside air into the ESP.

During PEDCo's visit to the plant on May 21, 1977, Phelps Dodge personnel indicated that one hanging damper is installed in each of the two equally sized inlet ducts to the ESP. These dampers may differ slightly in size and thus be causing differences in velocity and gas dust loadings in the two ducts. The flip-flop damper (installed in the duct system for guiding gases through the balloon flue or the duct work), the manholes on the ESP, and the access doors on the hoppers are all possible sources of air infiltration.

Average grain loading measurements using instack filters are based on five simultaneous test runs conducted July 8, 9, and 10, 1976, at the two inlet ducts and the outlet duct of the ESP. Problems were encountered during the test program because of the sticky or tacky nature of particulates, which cause them to plug the filtering media at the ESP inlet (and to a lesser extent at the ESP outlet). The average inlet and outlet particulate concentrations are 1.37 and 0.046 g/m^3 (0.6 and 0.02 gr/scf) respectively. These averages are calculated without regard for ESP inlet grain loading changes in the operating cycle of the reverberatory furnace. At the 95 percent confidence level, therefore, the inlet particulate loading is 1.38 ± 0.586 g/m^3 (0.603 ± 0.256 gr/scf) and the outlet loading is 0.046 ± 0.0075 g/m^3 (0.0202 ± 0.0033 gr/scf). During all five of the simultaneous test readings at the inlet ducts, loading measurements varied significantly. If it were possible to take inlet concentration measurements in the mixing chamber, the results might be more accurate.

Conclusions concerning the amount of condensables between 315° and 120°C (600 and 250°F), are based on tests using instack and outstack filter tests. This determination was, in essence, a comparison between instack filter and outstack filter sampling methods. The results presented in Table 3-7 are based on two measurements performed at a single point in the west inlet duct and three measurements with a six-point traverse at the outlet duct.

Table 3-7. INSTACK VS. OUTSTACK PARTICULATE LOADING

PHELPS DODGE CORPORATION, AJO, ARIZONA

Run	ESP Inlet			ESP Outlet		
	Instack	Outstack	Combined	Instack	Outstack	Combined
1	1.33 g/m^3 (0.58 gr/scf)	4.32 g/m^3 (1.89 gr/scf)	5.65 g/m^3 (2.47 gr/scf)	0.062 g/m^3 (0.027 gr/scf)	2.15 g/m^3 (0.94 gr/scf)	2.22 g/m^3 (0.97 gr/scf)
2	0.71 g/m^3 (0.31 gr/scf)	2.86 g/m^3 (1.25 gr/scf)	3.57 g/m^3 (1.56 gr/scf)	0.16 g/m^3 (0.072 gr/scf)	1.78 g/m^3 (0.78 gr/scf)	1.92 g/m^3 (0.84 gr/scf)
3				0.044 g/m^3 (0.019 gr/scf)	3.09 g/m^3 (1.35 gr/scf)	3.14 g/m^3 (1.37 gr/scf)

As indicated by test results using only an instack filter, the loading varies significantly in the two ducts at any given time. The instack and outstack filter tests at the ESP inlet also should have been conducted at more than one sampling point in both ducts. Results do not indicate whether the test runs were taken continuously, or at different times to allow for the effect of the furnace operation on the loadings. Tests using an instack filter train and an instack/outstack filter train might be more valuable if they were conducted at the same time and if measurements were taken repeatedly at different intervals to allow for variations in particulate loading that result from operating changes. Tabular data in Table 3-7 (two measurements) show that 77 to 80 percent of the total particulate entering the ESP's is in a vapor form. The overall removal efficiency of the ESP is 46 to 61 percent. The particulate measurements were obtained by using instack/outstack filter trains at the inlet and outlet of the ESP. The instack filter was at 316°C (600°F) and the outstack filter at 120°C (250°F). These measurements also indicate that the ESP's are removing from 77 to 98 percent of the particulate in a solid state at 316°C (600°F) and 38 to 50 percent of particulates in the supposedly gaseous state at 316°C (600°F). This poses a question as to how 38 to 50 percent of gaseous particulate is removed in the ESP.

Radian also conducted sampling tests on July 11, 1976, at the inlet and outlet of the ESP to capture all particulate trace elements in the gas streams. They used a train containing a wet electrostatic precipitator (WESP), followed by a series of impingers to collect vapors escaping the ESP. They also analyzed the dust collected in the ESP by periodic sampling. These ESP inlet and outlet samples were collected isokinetically from a single point assumed to be a point of average velocity and particulate loading. The sample collected was analyzed for trace elements by the atomic absorption method and fluorometry. The results indicate that nearly all the trace elements were collected in the WESP, whereas only negligible amounts were collected by the impingers.

On July 13, 1976, Radian also measured the trace elements content of the flue gas at the ESP outlet, using a WESP sampler followed by impingers; that was part of a sampling program for material balance around the reverberatory furnace. They conducted a separate test on July 16, 1976, for trace elements present as vapor in the flue gas at the ESP outlet. The collection of vapor phase trace elements was accomplished using a series of impingers, preceded first by a cyclone then by a filter to remove particulates. Table 3-8 presents the results of these tests/analyses of the total particulate (in the flue gas at ESP inlet and outlet) and vapor phase particulate (in the flue gas at ESP outlet). Because the values for solid phase trace elements collected on the cyclone and filter were not measured during the test for vapor phase trace elements, it is impossible to estimate accurately the relative proportions of these phases in the flue gas at the ESP outlet. The WESP samples indicate that the ESP now used removes about 26 percent of the arsenic in the gas (results of particulate measured on July 11, 1976, from Table 3-8). Results also show that some copper and small amounts of cadmium, lead, and zinc present in the inlet gas were also removed in the following proportions: 98.2, 94.2, 91.6, and 98.1 percent respectively.

Results of the quantitative analysis of samples collected around the reverberatory furnace are given in Table 3-9. As shown in Table 3-6, integral WESP samples at the

Table 3-8. ANALYSES OF TOTAL PARTICULATE AND VAPOR PHASE PARTICULATE IN FLUE GAS AT ESP INLET OR OUTLET (BY RADIAN CORPORATION)

Element	ESP inlet Total particulate measured on 7/11/76[a,b]		Total particulate measured on 7/11/76[a,c]		ESP outlet Total particulate measured on 7/13/77[d]		Vapor phase content measured on 7/16/77	
	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr
Arsenic	86.2	190	63.5	140	34.5	76	6.8	15
Barium	Not detected		Not detected		0.29	0.64	0.12	.27
Beryllium	0.0059	0.013	0.0049	0.011	0.0015	0.0034	0.0018	0.004
Cadmium	0.13	0.29	0.0073	0.016	3.45	7.6	0.00004	0.0001
Chromium	0.012	0.027	0.0049	0.011	0.019	0.044	0.016	0.036
Copper	25.4	56	0.454	1.0	8.16	18	1.33	2.94
Fluorine	3.36	7.4	3.4	7.5	4.26	9.4	4.99	11.0
Iron					0.249	0.55	0.089	0.196
Mercury	0.00049	0.0011	0.00039	0.00087	0.015	0.033	0.028	0.062
Molybdenum	3.95	8.7	0.073	0.16	0.077	0.17	0.0073	0.016
Nickel	0.042	0.092	0.039	0.085	0.0049	0.011	0.014	0.031
Lead	0.42	0.92	0.034	0.075	0.17	0.38	0.0039	0.0087
Sulfur as SO_2[e]	598.7	1320	1002.4	2210				
as SO_3[e]	13.61	30	22.67	50				
Antimony	0.367	0.81	0.149	0.33	.014	0.03	0.0014	0.003
Selenium	0.413	0.91	0.439	0.97	0.295	0.65	0.095	0.21
Silica						1.7		
Vanadium	0.018	0.041	0.002	0.0047	0.77	0.027	0.009	0.02
Zinc	1.95	4.3	0.033	0.072	0.099	0.22	0.016	0.036

[a] Particulate collected using wet electrostatic precipitator (WESP). In addition to this, an insignificant amount of trace elements is collected on impingers.

[b] Trace elements constituted 0.32 percent of total sample analyzed.

[c] Trace elements constituted 0.12 percent of total sample analyzed.

[d] Trace elements constituted 0.1 percent of total analyzed

[e] Sample was not analyzed for sulfur, but its values are based on SO_2-SO_3 concentrations in flue gas and the sulfur content of the flue dust, determined independently of the WESP sampler.

Table 3-9. ELEMENT FLOW RATES IN THE FEED AND DISCHARGE STREAMS OF REVERBERATORY FURNACE

	Incoming streams						Outgoing streams										
	Reverb. feed		Converter slag	Converter dust	Total		Matte		Slag		Flue gas		ESP[a] dust		Waste heat[a] boiler dust	Total	
Element	kg/hr	lb/hr			kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr		kg/hr	lb/hr
Al	181	400	NA	NA	181	400	<7.7	<17	318	700	0.045	0.10	0.49	1.1	NA	318	700
As	86.4	190	NA	NA	86.0	190	0.72	1.59	0.86	1.9	34.5	76	13.6	30	NA	49.4	109
Ba	14.4	31	NA	NA	14.1	31	14.97	33	19.5	43	0.29	0.64	0.010	0.023	NA	34.6	76.2
Be	0.032	0.072	NA	NA	0.032	0.072	0.0019	0.0041	0.015	0.032	0.0015	0.0034	0.0002	0.0004	NA	0.014	0.039
Ca	349	770	NA	NA	349	770	5.4	12	862	1900	0.005	0.011	0.95	2.1	NA	907	2000
Cd	26.7	59	NA	NA	26.7	59	16.8	37	0.15	0.33	3.44	7.6	0.33	0.74	NA	20.9	46
Cr	0.034	0.076	NA	NA	0.034	0.076	29	0.64	1.72	3.8	0.019	0.044	0.0082	0.018	NA	2.04	4.5
Cu	7260	16000	NA	NA	7260	16000	8165	18000	998	2200	8.16	18	28	62	NA	8165	18000
F	1.5	3.4	NA	NA	1.54	3.4	0.005	0.012	1.0	2.2	4.26	9.4	0.015	0.032	NA	5.4	12
Fe	4536	10000	NA	NA	4536	10000	4970	11000	5443	12000	0.25	0.55	19.3	42.6	NA	10400	23000
Hg	0.0082	0.018	NA	NA	0.008	0.018	0.0091	0.020	0.004	0.0091	0.015	0.033	0.00007	0.00015	NA	0.028	0.062
Mo	35.8	79	NA	NA	35.8	79	3.85	8.5	40.3	89	0.077	0.17	2.99	6.6	NA	45.4	100
Ni	0.32	0.70	NA	NA	0.32	0.70	0.91	2.0	0.34	0.76	0.0050	0.011	0.026	0.059	NA	13.2	29
Pb	22.2	49	NA	NA	22.2	49	38.1	84	5.89	13	0.17	0.38	2.4	5.3	NA	45.4	100
Sb	2.72	6.0	NA	NA	2.72	6.0	2.09	4.6	1.54	3.4	0.014	0.030	0.58	1.3	NA	4.26	9.4
Se	4.54	10	NA	NA	4.54	10	0.077	0.17	2.49	5.5	0.29	0.65	0.073	0.16	NA	2.95	6.5
Si	499	1100	NA	NA	499	1100	<19	<42	21.7	48	0.77	1.7	0.77	1.7	NA	2177	4800
V	0.42	0.92	NA	NA	0.42	0.92	0.15	0.33	0.39	0.86	0.12	0.027	0.005	0.011	NA	0.54	1.2
Zn	19.0	42	NA	NA	19.0	42	14.1	31	13.6	30	0.10	0.22	2.09	4.6	NA	29.9	66

[a] These streams were not recycled during the time of ESP sampling

NA - Not available.

ESP outlet were collected on July 13, 1976, and precipitator dust was collected July 11 to 13, 1976. The matte and slag were obtained during sampling from July 12 through July 14, 1976. The samples of concentrate were taken at the end of each shift from January 12 to 14, 1976. The data in Table 3-8 and Table 3-9 show that of a total of 86.2 kg/hr (190 lb/hr) of arsenic entering the system only 34.5 to 63.5 kg/hr (76 to 140 lb/hr) is found in the ESP exit stream and 13.6 kg/hr (30 lb/hr) is trapped in the ESP dust. According to Radian, the remaining 7.3 to 36.3 kg/hr (16 to 80 lb/hr) of arsenic, which is unaccounted for, may have settled out in the surface area of the waste-heat boilers serving the reverberatory furnace. As indicated in the table, some of the other elements may also be settling out in the waste-heat boilers.

On July 13 and 14, 1976, Radian conducted a separate test for arsenic at the ESP inlet and outlet, using EPA Method 5 with a filter at 120°C (250°F) followed by a series of impingers. During these tests, Radian measured arsenic emission rates averaging 31.39 kg/hr* (69.2 lb/hr) at the ESP inlet [measurements of 26.9 kg/hr (59.3 lb/hr), 33.1 kg/hr (72.9 lb/hr), and 34.2 kg/hr (75.4 lb/hr) during three runs] and 22.6 kg/hr (49.9 lb/hr) at the ESP outlet [measurements of 24.4 kg/hr (53.7 lb/hr), 20.3 kg/hr (44.8 lb/hr), and 23.3 kg/hr (51.3 lb/hr) during three runs]. These data do not clearly indicate whether the arsenic emission rates are based on the amount collected on the filter at 120°C (250°F) only, or on the total amount collected on the filter and impingers.

Based on these sampling tests, Radian assumes that the efficiency of the WESP used for sample collection in this study can be compared with the expected efficiency of the WESP for particulate control. They further assume that virtually all elements covered in their study can be collected in the spray tower, packed tower, and WESP arrangement. The blowdown stream of the cooling-humidifying unit, however, will have to be treated, because it will contain all the impurities presently escaping the existing dry ESP that treats the off-gases of the reverberatory furnace.

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* The emission rates are based on flow rate determined by Radian and analyzed data obtained by Battelle, Columbus Laboratories, Columbus, Ohio.

Additional tests produced the following results: the reverberatory feed concentrate consists primarily of two crystalline phases: chalcopyrite ($CuFeS_2$) and two-quartz (SiO_2). Arsenolite (As_2O_3) was positively identified in the hopper dust, in the material captured by the instack filter, in the deposit on the outstack filter as well as in the impingers. Hydrates of copper sulfate and arsenolite were the predominant materials collected on the instack filter. This material was a bright blue, and the crystalline portion was almost pure arsenic oxide. The crystalline portion of the material collected on the outstack filters at 120°C (250°F) was almost all arsenolite.

Aerotherm Corporation Test Results

At the request of EPA Region IX, Aerotherm conducted particulate emission tests from July 20 to July 30, 1976, on the ESP outlet of the reverberatory furnace, the acid plant, and the main stack. This was done to determine the compliance status of the copper smelter with the process weight particulate emission regulation. During the testing period, particulate emissions and concentrations of SO_3/H_2SO_4 and SO_2 were measured, and the instack sampling method was compared with EPA Method 5. Table 3-10 summarizes the actual time during which test samples were taken at the reverberatory furnace ESP. Two trains were used during the

Table 3-10. SUMMARY OF SAMPLING TIMES -
REVERBERATORY ESP

Run No.	Date	Sampling time		
1	7-20-76	A-Port	4:15 pm	4:45 pm
		B-Port	4:58 pm	5:28 pm
2	7-21-76	A-Port	5:25 pm	5:55 pm
		B-Port	6:00 pm	6:30 pm
3	7-22-76	A-Port	9:56 am	10:26 am
		B-Port	10:29 am	10:59 am
4	7-23-76	A-Port	9:18 am	9:48 am
		B-Port	9:53 am	10:23 am
5	7-26-76	A-Port	8:50 am	9:20 am
		B-Port	9:25 am	9:55 am
6	7-26-76	A-Port	2:56 pm	3:26 pm
		B-Port	3:27 pm	3:57 pm
7	7-27-76	A-Port	8:35 am	9:05 am
		B-Port	9:08 am	9:38 am
8	7-28-76	A-Port	11:13 am	11:43 am
		B-Port	11:44 am	12:14 pm
9	7-28-76	A-Port	7:16 pm	7:46 pm
		B-Port	7:49 pm	8:19 pm
10	7-29-76	A-Port	10:12 am	10:42 am
		B-Port	10:50 am	11:20 am
11	7-29-76	A-Port	4:00 pm	4:30 pm
		B-Port	4:34 pm	5:04 pm
12	7-30-76	A-Port	11:20 am	11:50 am
		B-Port	11:55 am	12:25 pm

testing: one sampling train for a combination of EPA Methods 3 and 4, to measure gas composition moisture content; and one sampling train for a combination of EPA Methods 5 and 8, to measure particulate and sulfur oxide emissions. The two trains were used simultaneously, one in each sample port.

Aerotherm based the following conclusions and observations on the test results: a) particulate emissions from the ESP are much greater than the allowable particulate emission rate; b) the amount of particulate measured when using a train with both instack and outstack filters is consistently higher than the amount measured when using a sampling train with only an outstack filter (according to the EPA Method 5 test procedure, required for process weight emissions regulation); c) particulates captured on both the instack and outstack filters are hygroscopic in nature, with a difference between extrapolated and equilibrium weights of 20 to 40 percent on the instack filter and 30 to 50 percent on the outstack filter; d) a large portion of the particulate collected may be sulfuric acid; and e) a chemical analysis of the particulate should be undertaken to determine its characteristics.

To calculate allowable emissions, reverberatory furnace process weight data were collected for an 8-hr shift on July 26, 1976. These data are summarized in Table 3-11.

Table 3-11. TOTAL SOLID INPUT TO THE REVERBERATORY FURNACE DURING SHIFT "A" (8-HR PERIOD) ON JULY 26, 1976 (ESTIMATED BY THE PHELPS DODGE STAFF)

Input	Quantity	
	metric tons	tons
Concentrate	159	175
Converter slag	105	116
Precipitate	5.4	6
Lime	13.6	15
Dust	7.3	8
Total	290.3	320

The corresponding allowable emission rate based on the process weight regulation would be 14.15 kg/hr (31.2 lb/hr).

It was observed during the sampling program that 2 hours of the total time cycle for normal converter operation are generally required for a copper-blow. Table 3-12 records the test results of a sample train using EPA Methods 3 and 4. Table 3-13 records the test results of a sample train using EPA Methods 5 and 8. Because of the hygroscopic nature of the particulate matter collected, the filter gained weight very rapidly during the weighing process by adsorbing water vapor from the air. Consequently, no attempt was made to determine the exact weight of the filter on completion of sampling. It was weighed later to calculate equilibrium weight, from which extrapolated emission weights were calculated. Of the 12 measurements taken, Runs 2 through 9 were made by an EPA Method 5 sample train, and the remaining runs were made by a sample train containing an instack filter and an outstack filter. Because of subisokinetic sampling rates, Runs 1 and 11 on Table 3-13 were rejected.

Table 3-12. SUMMARY OF SAMPLING DATA USING EPA METHODS 3 AND 4 - PHELPS DODGE REVERBERATORY FURNACE ESP

No.	Date (1976)	Moisture %	Vm-dry volume measured by meter		CO_2 %	O_2 %	Md[a] kg/kg mole or lb/lb mole	Ms[b] kg/kg mole or lb/lb mole	VS-gas velocity		Qs-gas flow rate	
			m^3	scf					m/sec	ft/sec	m^3/hr $\times 10^4$	scfh $\times 10^6$
1	July 20	16.8	1.03	36.5	1.0	18.1	29.16	27.29	23.2	76.0	8.78	3.1
2	July 21	12.3	1.27	44.8	1.0	18.1	28.88	27.54	24.8	81.4	10.2	3.6
3	July 22	12.3	1.17	41.3	3.7	11.3	29.05	28.03	21.3	69.9	8.49	3.0
4	July 23	12.3	1.25	44.2	0.9	18.1	28.86	27.53	25.7	84.3	10.76	3.8
5	July 26	12.8	1.13	39.9	4.2	14.0	29.23	27.80	18.8	61.8	7.93	2.8
6	July 27	10.1	1.26	44.7	4.2	14.0	29.23	28.10	23.6	77.4	10.2	3.6
7	July 28	12.3			4.2	14.0						
8	July 28	9.0	1.13	39.9	5.9	11.3	29.39	28.36	27.5	90.1	11.89	4.2
9	July 28	11.1	1.41	49.9	6.2	10.9	29.43	28.16	25.4	83.3	109.8	38.8
10	July 29	12.1	1.28	45.2	6.3	10.5	29.43	28.05	23.6	77.5	11.04	3.9
11	July 29	11.5	1.28	45.3	5.8	11.5	29.39	28.08	23.5	77.1	11.04	3.9
12	July 30	13.8	1.28	45.2	5.8	11.5	29.39	27.83	21.9	72.1	10.2	3.6

[a] Md - dry molecular weight.

[b] Ms - wet molecular weight.

Table 3-13. SUMMARY OF PARTICULATE, SO_3/H_2SO_4 AND SO_2 EMISSION DATA FOR REVERBERATORY FURNACE ESP

Run No.[a]	Date (1976)	Particulate concentration			Particulate emission rate				Allowable emission rate	SO_2 concentration	SO_2 emission rate	SO_3/H_2SO_4 concentration	SO_3/H_2SO_4 emission rate
		Extrapolated weight	First measured weight	Equilibrium weight	Extrapolated weight	First measured weight	Equilibrium weight	Percent Isokinetic					
1	July 20	1.67 g/m^3 (0.731 gr/scf)	1.68 g/m^3 (0.732 gr/scf)	2.14 g/m^3 (0.934 gr/scf)	149 kg/hr (328.3 lb/hr)	149 kg/hr (328.6 lb/hr)	190 kg/hr (419.5 lb/hr)	87.0%	14.2 kg/hr (31.3 lb/hr)	9660 ppm	2270 kg/hr (5000 lb/hr)	16.4 ppm	4.72 kg/hr (10.5 lb/hr)
2	July 21	1.41 g/m^3 (0.617 gr/scf)	1.41 g/m^3 (0.617 gr/scf)	1.72 g/m^3 (0.752 gr/scf)	144 kg/hr (318.2 lb/hr)	144 kg/hr (318.4 lb/hr)	176 kg/hr (388.1 lb/hr)	91.4%	14.2 kg/hr (31.4 lb/hr)	15,820 ppm	4320 kg/hr (9500 lb/hr)	49.7 ppm	16.9 kg/hr (37.2 lb/hr)
3	July 22	1.46 g/m^3 (0.639 gr/sdf)	1.46 g/m^3 (0.640 gr/scf)	1.83 g/m^3 (0.801 gr/scf)	124 kg/hr (272.9 lb/hr)	124 kg/hr (273.2 lb/hr)	155 kg/hr (341.9 lb/hr)	109.2%	14.3 kg/hr (31.6 lb/hr)	6760 ppm	1500 kg/hr (3300 lb/hr)	27.0 ppm	7.6 kg/hr (16.8 lb/hr)
4	July 23	0.92 g/m^3 (0.400 gr/scf)	0.92 g/m^3 (0.400 gr/scf)	1.40 g/m^3 (0.612 gr/scf)	97.9 kg/hr (216.2 lb/hr)	97.9 kg/hr (216.5 lb/hr)	98.3 kg/hr (216.5 lb/hr)	92.0%	14.5 kg/hr (31.9 lb/hr)	6340 ppm	1810 kg/hr (4000 lb/hr)	2.9 ppm	1.04 kg/hr (2.3 lb/hr)
5	July 26	1.02 g/m^3 (0.444 gr/scf)	1.02 g/m^3 (0.444 gr/scf)	1.55 g/m^3 (0.679 gr/scf)	75.2 kg/hr (175.3 lb/hr)	79.6 kg/hr (175.6 lb/hr)	122 kg/hr (268.4 lb/hr)	107.7%	14.1 kg/hr (31.2 lb/hr)	4830 ppm	997 kg/hr (2200 lb/hr)	0.0 ppm	0.0 kg/hr (0.0 lb/hr)
6	July 26	1.49 g/m^3 (0.651 gr/scf)	1.49 g/m^3 (0.651 gr/scf)	1.95 g/m^3 (0.851 gr/scf)	150 kg/hr (330 lb/hr)	150 kg/hr (331.1 lb/hr)	196 kg/hr (432.8 lb/hr)	98.8%	13.8 kg/hr (30.5 lb/hr)	16,190 ppm	4320 kg/hr (9500 lb/hr)	12.8 ppm	10.8 kg/hr (24.0 lb/hr)
7	July 27								14.0 kg/hr (30.8 lb/hr)				
8	July 28	1.27 g/m^3 (0.555 gr/scf)	1.27 g/m^3 (0.555 gr/scf)	1.49 g/m^3 (0.652 gr/scf)	150 kg/hr (331.3 lb/hr)	150 kg/hr (331.7 lb/hr)	177 kg/hr (389.9 lb/hr)	96.3%	13.9 kg/hr (30.7 lb/hr)	5440 ppm	1720 kg/hr (3800 lb/hr)	0.0 ppm	0.0 kg/hr (0.0 lb/hr)
9	July 28	1.14 g/m^3 (0.500 gr/scf)	1.23 g/m^3 (0.538 gr/scf)	1.64 g/m^3 (0.716 gr/scf)	125 kg/hr (273.3 lb/hr)	133 kg/hr (293.9 lb/hr)	178 kg/hr (390.9 lb/hr)	104.0%	14.4 kg/hr (31.7 lb/hr)	1810 ppm	500 kg/hr (1100 lb/hr)	42.5 ppm	15.2 kg/hr (33.7 lb/hr)
10	July 29	1.73 g/m^3 (0.758 gr/scf)	1.74 g/m^3 (0.760 gr/scf)	2.24 g/m^3 (0.980 gr/scf)	192 kg/hr (423.0 lb/hr)	192 kg/hr (423.8 lb/hr)	310 kg/hr (683.8 lb/hr)	92.8%	14.3 kg/hr (31.5 lb/hr)	7430 ppm	2180 kg/hr (4800 lb/hr)	41.1 ppm	15.0 kg/hr (33.0 lb/hr)
11	July 29	1.78 g/m^3 (0.780 gr/scf)	1.78 g/m^3 (0.777 gr/scf)	2.17 g/m^3 (0.951 gr/scf)	197 kg/hr (431.8 lb/hr)	197 kg/hr (433.6 lb/hr)	240 kg/hr (528.2 lb/hr)	89.7%	14.1 kg/hr (31.01 lb/hr)	3810 ppm	1090 kg/hr (2400 lb/hr)	40.6 ppm	14.8 kg/hr (32.7 lb/hr)
12	July 30	1.86 g/m^3 (0.816 gr/scf)	1.89 g/m^3 (0.829 gr/scf)	2.30 g/m^3 (1.004 gr/scf)	192.2 kg/hr (423.9 lb/hr)	195 kg/hr (430.4 lb/hr)	237 kg/hr (521.6 lb/hr)	98.1%	14.3 kg/hr (31.6 lb/hr)	8340 ppm	2270 kg/hr (5000 lb/hr)	44.9 ppm	15.4 kg/hr (33.9 lb/hr)

[a] Runs 1 and 11 are rejected because of subkinetic conditions. Runs 10, 11, and 12 were done by using instack/outstack filter trains. During test runs 10 and 12, the particulate emission rate using the instack filter was 98.52 (217.2) and 96.52 kg/hr (212.8 lbs/hr) respectively.

The measurements of Run 7 were not considered, because of errors in velocity measurements and isokinetic sampling rates. The velocity measurement on one of the trains was low in Run 5, and the measured emission rate reading was replaced with a corrected emission rate, which is an average of all particulate emissions collected on the outstack filters.

During the test program, Aerotherm observed that, for some undetermined reason, the Teflon^R coating on the outstack filter holder broke down and flaked at 120°C (250°F) in each test. Since any particulates that may have been deposited on these Teflon^R flakes would not be included in the actual particulate measurements, Aerotherm believes the measured emission rate to be erroneously low. The magnitude of this error could not be measured.

Aerotherm calculated a mean particulate emission rate of 143.4 kg/hr (316.1 lb/hr) and a standard deviation of 32.4 (71.4), using all the valid measurements, including seven EPA test methods, five runs, and two simultaneous instack and outstack test runs.

The data indicated a mean particulate emission rate of 129.5 kg/hr (285.44 lb/hr) with a standard deviation of 21.8 (48.13) using EPA Method 5. Using a 95 percent confidence level, the limits become 129.5 ± 14.4 kg/hr (285.44 ± 31.67 lb/hr). A comparison of the average particulate emission rate of 129.5 kg/hr (285.44 lb/hr) by EPA Method 5 with the average particulate emission rate of 192.1 kg/hr (423.45 lb/hr) (average of two measurements) by a combination of instack and outstack filters indicates that about 50 percent more particulate is collected by the latter than by the former. Aerotherm could not explain the weight difference of the residues from the two sampling trains.

During instack/outstack testing, emissions collected on the instack filter and residue from the nozzle and probe were included with the instack filter weight. The average particulate weight collected on the nozzle, instack filter, and probe during two instack/outstack test runs was 96.5 kg/hr (212.8 lb/hr), which is about 50 percent of the total collected on the nozzle, instack filter, probe and outstack filter. Comparison of the average particulate emission of 96.5 kg/hr (212.8 lb/hr) measured on the nozzle, instack filter, and probe with the average particulate emissions of 129.5 kg/hr (285.44 lb/hr) measured by EPA Method 5, shows that the amount collected by EPA Method 5 is about 134 percent of the amount collected by the former method.

Calculated mean emission rates of SO_3/H_2SO_4 and SO_2 from the test data were 11.2 kg/hr (24.9 lb/hr) with a 5.62 kg/hr (12.4 lb/hr) standard deviation, and 2313.4 kg/hr (5100 lb/hr) with a 1134 kg/hr (2500 lb/hr) standard deviation respectively.

SRI Test Results

Southern Research Institute performed tests July 9, and 10, 1976, to measure the fractional collection efficiency and the voltage-current characteristics of the ESP system. A computer simulation of ESP performance was made simultaneously, using a computer system model developed by SRI, and the inlet particle size distribution was measured. The Institute concluded the following on the basis of the test results: a) Measured efficiency and design efficiency are identical within the limits of experimental error. (An overall collection efficiency of 96.7 percent was measured by instack filters, 96.6 percent was calculated from cascade impactor data, 96.8 is predicted by the SRI-EPA computer model, and 96.8 percent is the design efficiency.) b) Power supply versus electrical current characteristics indicates the ESP is in good mechanical alignment and electrical condition. c) Particulate resistivity is not limiting the operating characteristics of the collector. d) Particle sizes apparently differ in chemical composition. The mass median diameter of the inlet particle size distribution was greater than 10 µm. The inlet particle distribution was bimodal with one component having a mass median diameter less than 1 µm. e) A significant variation in sulfur dioxide concentration occurs with time. f) A potential problem with the application of an ESP to a source of very fine particulate is presented in suppression of the corona current by a particulate space charge. Some reduction in current was observed at the ESP inlet during the testing, but the degree of suppression was not large. This results from the particles being larger than expected. Furthermore, the concentration was rather low, and it was observed that some of the impactor catches appeared to be hygroscopic. The difference in the color of particles noted from stage to stage within the impactor indicates that their chemical composition was nonhomogeneous with respect to size.

Six measurements were made of the particle size distribution during the test, three each at the inlet and outlet, using a modified Brink cascade impactor. Southern Research Institute noted that the validity of the first outlet run data was questionable because the filter and filtrates for this run were discovered to be wet when the impactor was disassembled. This was probably caused by condensed water within the probe as it accidentally ran back into the impactor after being removed from the duct.

Figure 3-1 presents a plot of the average inlet and outlet size distributions on a cumulative percentage basis versus particle size basis for the Phelps Dodge smelter. Figure 3-2 shows measured and calculated fractional efficiency

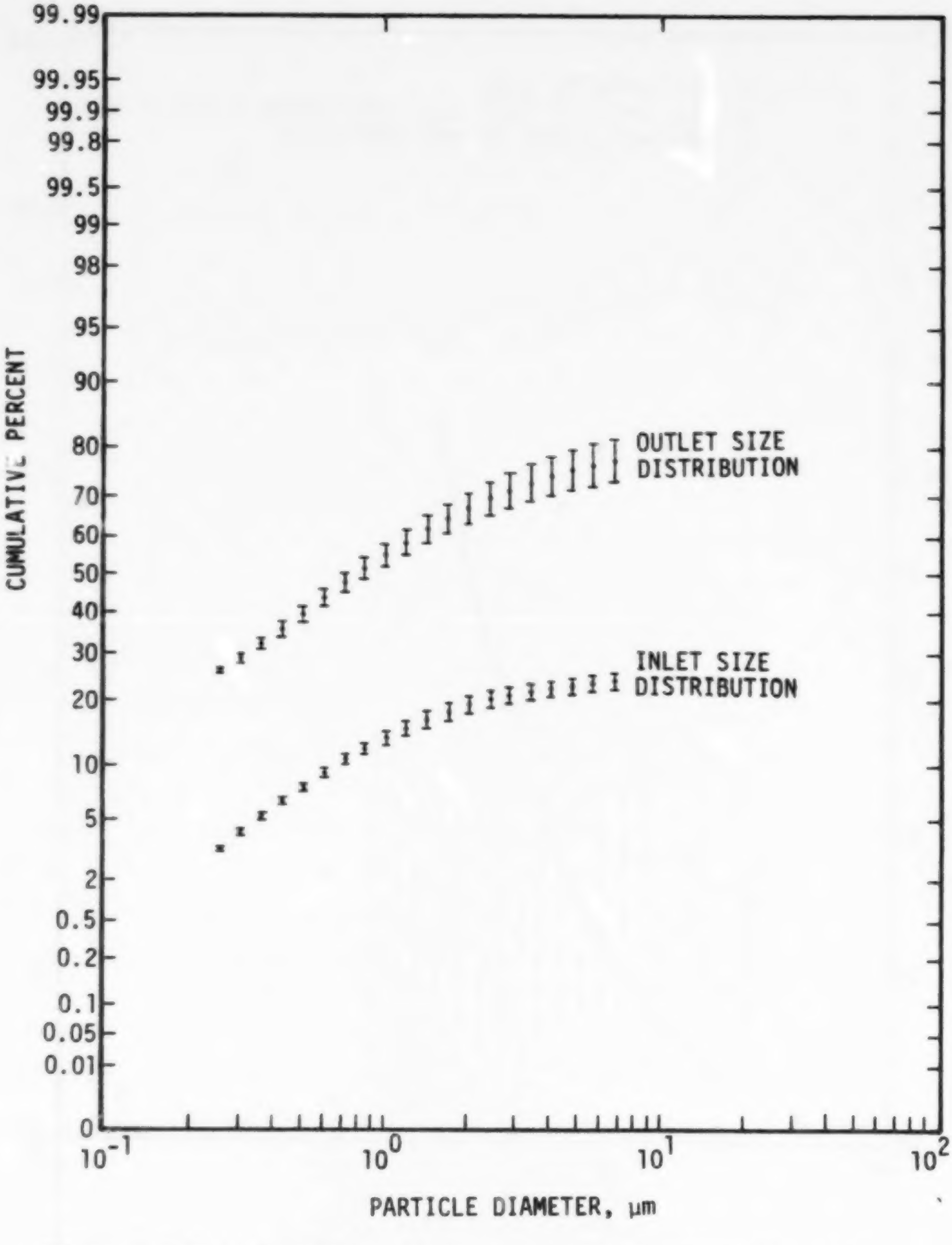

Figure 3-1. Average inlet and outlet particle size distributions, particle size vs. cumulative percent, for the ESP at the Phelps Dodge smelter.

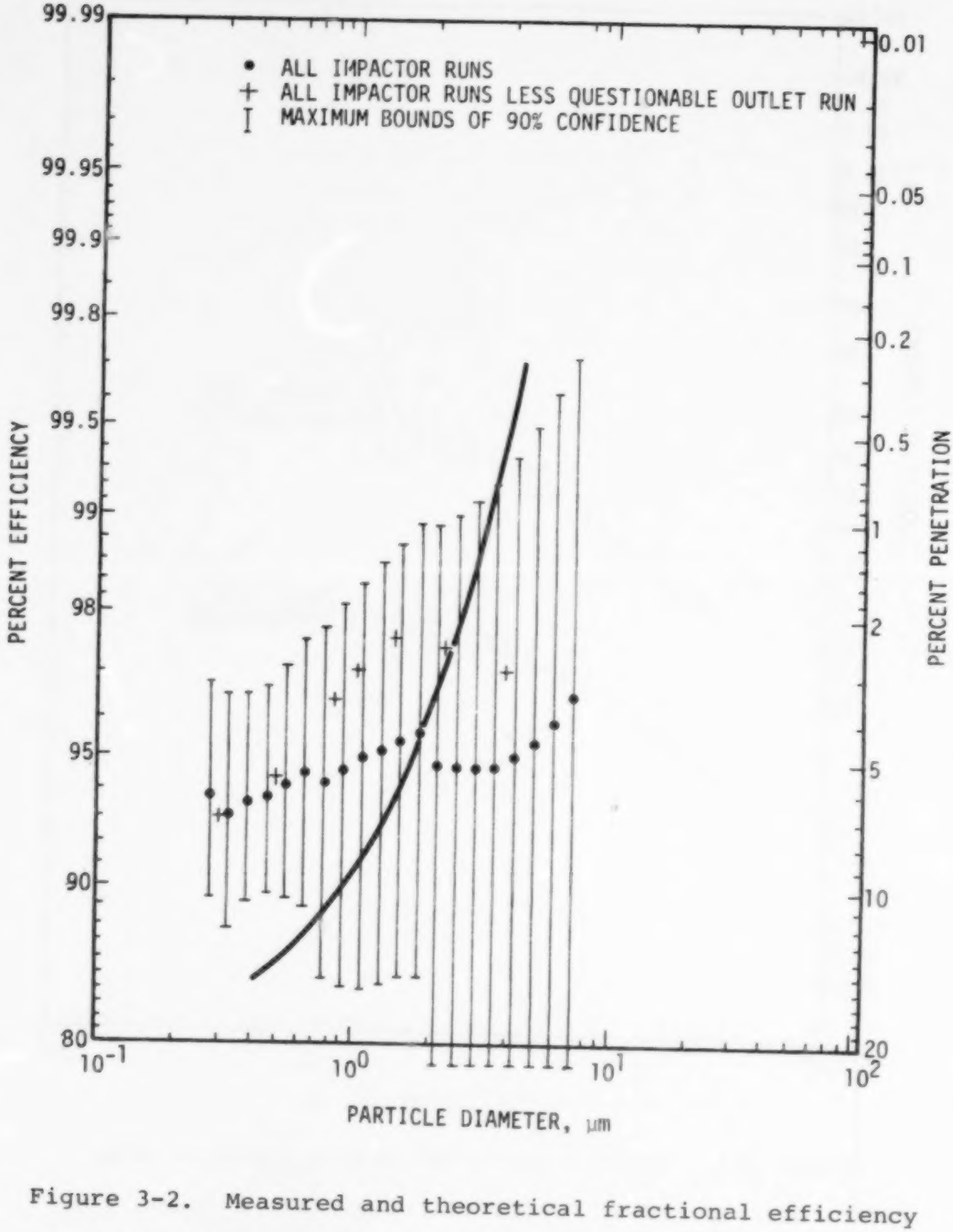

Figure 3-2. Measured and theoretical fractional efficiency curves prepared by SRI for the ESP on the reverberatory furnace at Phelps Dodge Corporation.

curves for the reverberatory furnace ESP. The theoretical curve generated with the SRI-EPA computer model simulation is predicted for ideal conditions, with no corrections for rapping losses, poor velocity distribution, or any of the gas bypassing the active areas.

The inlet particulate size distribution is bimodal, with a fine mode having a mass median diameter of 0.8 μm. Approximately 22 percent of the mass is contained in particles with diameters smaller than 10 μm (Figure 3-1). The overall mass median diameter of the inlet particle size distribution is greater than 10 μm. It is also evident from Figure 3-1 that less than 3 percent of the total mass is 0.26-μm in size. Approximately 80 percent of the total mass collected at the ESP outlet was under 10 μm in size. About 26 percent was below 0.26 μm.

On July 9 and 10, 1976, ESP efficiency measurements of 96.4 and 96.7 percent were made using an impactor train and 96.6 and 96.8 percent using a mass train. Mass emission data were provided to SRI by the Radian Corporation from simultaneously conducted tests.

Southern Research Institute indicated that the impactor data may not be reliable, especially regarding particle size at the ESP outlet, because of their inability to do isokinetic traverses and the low quantities collected on impactor stages. During each sampling, anywhere from one-tenth to a few tenths milligram weight was collected on each stage. Figure 3-2, which presents the confidence limits, shows the unreliability of the data.

On July 9 and 10, 1976, SO_2 sample measurements were made at the ESP outlet using a sampling system consisting of a heated, glass-lined sampling probe with a quartz wool filter, a water-jacketed condenser, and fritted bubbler containing a 3 percent hydrogen peroxide solution. The measurements were made before and after the reverberatory furnace was charged, because the sulfur oxide concentration is expected to vary with the furnace operation cycle. Based on the test results presented in Table 3-14, SRI speculates that SO_2 concentrations in the stack gas are highly variable.

Table 3-14. TEST RESULTS - SULFUR OXIDE CONCENTRATION

(by volume percent)

Date	Furnace charge cycle	SO_2	SO_3
7/9/76	After charging	1.0	0.024
	Before charging	0.42	0.019
7/10/76	After charging	0.73	0.018
	Before charging	0.63	0.025
	After charging	1.7	0.067

Southern Research Institute concedes that the reliability of the SO_3 data cannot be verified because the applicability of this method of measurement to the nonferrous metal industry is questionable and the efficiency of the condenser has not been previously evaluated in this kind of environment; however, they do not believe this makes the accuracy of the SO_2 measurements suspect. They do suggest, however, that accurate measurement of SO_3 concentrations with respect to the furnace operation requires further investigation.

4.0 ADD-ON CONTROL SYSTEM FOR PARTICULATE EMISSIONS

As explained in Section 2.0, the principal reverberatory furnace exhaust gases at the Magma Copper Company and Phelps Dodge Corporation smelters pass through waste-heat boilers, after which the partially cooled gases are treated in ESP's before being vented through a stack. The ESP's were designed to treat the flue gases at a temperature of 316°C (600°F). The efficiency was to be determined by using the ASTM test method. This method specifies that particulate loading of the flue gas be measured at a process gas temperature, which is about 316°C (600°F) at these two smelters. The copper reverberatory furnaces at these smelters are presently subject to compliance with EPA Process Weight Regulation 40 CFR 52.126(b), which requires the flue gas particulate content to be measured at about 120°C (250°F) in accordance with EPA Method 5. Most of the flue gas particulate matter at these two smelters, as measured by Method 5, is composed of material that has condensed from the vapor phase to the solid or liquid phase when the gas temperature is reduced from 316°C (600°F) to 120°C (250°F) in the sampling apparatus. Numerous sampling tests conducted for EPA by different organizations have shown that the reverberatory furnaces at the Magma Copper and Phelps Dodge smelters are emitting more particulate matter than allowed by the EPA Process Weight Regulation.

The EPA decided to evaluate the feasibility of upgrading control systems of these smelters as a means of meeting emission standards, and also (with the assistance of IGCI) to evaluate new control alternatives if upgrading proves impractical. The EPA provided various sampling test data obtained at the two smelters for examination by IGCI and PEDCo. Based on the limited information provided and their best judgment, IGCI members believe each of the smelters can comply with EPA regulations by installing an additional control system in series with the ESP already in operation.

Effective particulate control can be achieved by first cooling the gas from the existing ESP outlet, then applying available control techniques such as electrostatic precipitation, filtration, or scrubbing. IGCI suggested one of the following add-on control systems be installed in series with the existing ESP's:

a) Gas cooling equipment to reduce flue gas temperature to 120°C (250°F) and a fabric filter to reduce the flue gas dust loading to an allowable level.

b) Gas cooling equipment to reduce flue gas temperature to 120°C (250°F) and a wet scrubber system to reduce the flue gas dust loading to an allowable level.

c) Gas cooling equipment to reduce flue gas temperature to 120°C (250°F) and a dry ESP to reduce the flue gas dust loading to an allowable level.

d) Gas cooling equipment to reduce flue gas temperature to 120°C (250°F) and a wet ESP to reduce the flue gas dust loading to an allowable level.

PEDCo also analyzed the sampling test data provided by EPA and developed technical specifications for the add-on control systems.

The specifications, which included data on flue gas exiting from the existing ESP such as volume flow rate, inlet gas loadings, allowable emissions, moisture content, and gas composition, were issued to selected IGCI members. They were asked to furnish capital and annual operating cost data for the add-on control systems specified. All provided costs for both gas cleaning equipment and auxiliary equipment, and some also provided direct and indirect cost items as well as annual operating cost data.

More definitive information on the nature of the flue gas would help in the development of precise technical and economical add-on particulate control systems for the smelters. Pilot plant studies of add-on control systems could determine their feasibility, optimum sizing, system pressure drop, and efficiency. Gas composition varies with raw materials, operating conditions, furnace production cycle, and also between smelters. Separate tests at the individual smelters, relating the emissions rate and composition with the smelter operating cycle, might provide better information on which to base control evaluations. The test program could also be extended to estimate condensation points of individual trace elements present in the gas and the dew point of the gas stream.

As mentioned previously, available data on the existing control systems at the Magma and Phelps Dodge smelters suggest that most of the particulate matter measured by EPA Method 5 was present as vapor at 316°C (600°F), but was condensed to a solid or liquid at 120°C (250°F). The process weight regulation requires flue gas particulates to be measured at 120°C (250°F) for compliance. If compliance is to be achieved, the gas must be cooled and the volatile compounds condensed before the gas passes through the add-on control equipment. This can be accomplished by evaporative cooling, dilution, or convection/radiation heat exchange. Because control by scrubbing is a wet operation, the gases are cooled by water as they pass through a quencher or scrubber.

Evaporative cooling with water (also known as spray cooling) has two principal advantages. First, this type of cooling does not greatly increase the gas volume, and second, it requires relatively little space. Consideration must be given to water availability and corrosion protection, however, when analyzing an evaporative cooling system.

Gas cooling with dilution air is the simplest method, but it is not economical because it greatly increases the gas volume flow rate to the add-on control system. This increased flow rate greatly increases the size and cost of the control device, and it could necessitate modifications to or replacement of the existing stack. Increased gas volumes would also decrease particulate concentrations in the gas at the inlet of the control system, thereby making it more difficult to achieve high particulate removal efficiencies.

Air-to-air heat exchangers have economic limitations and are disadvantageous for cooling larger gas volumes. They require a great deal of space, and the installed cost of this type of heat exchangers is also higher than any other cooling method.

Gas cooling by natural convection and radiation, causes the duct to become hot (because of the hot gas flowing through it), and it heats the surrounding air. Natural drafts are formed as the temperature of the air increases, carrying the heat away from the ducts. Heat is also discharged by radiant heat to the area surrounding the hot duct. Both temperature decreases in the hot gas flowing through a short duct length and temperature increases in the surrounding air are limited.

Those IGCI members who recommended dilution air cooling expressed the belief that this is the only technically feasible cooling method, despite obvious disadvantages. They rejected spray cooling because it would require the control device to be operated at a temperature lower than the acid dew point. They rejected the air-to-air heat exchanger because the skin temperature of the heat transfer surface would be below the acid dew point of the gas.

Data are not available on gas dew points for the smelters. However, calculations based on gas composition data indicate that the flue gas dew point is above 120°C (250°F). This could create corrosion problems in gas handling and treatment equipment. Some copper smelters that cool gases to temperatures as low as 93°C (200°F) before treatment use brick-lined flues and a brick and mortar stack with acid-proof lining.

At one copper smelter, gas from the fluid bed reactor, electric furnace, and converters is treated in a fabric filter control system; at three other smelters the gases are treated in a cold ESP. No wet scrubbers are used to control emissions from copper reverberatory furnaces in the United States. According to some IGCI members, fabric filters have been successfully used to clean reverberatory furnace gases at smelters in Canada.

An add-on control system must be equipped with a fan to handle the additional pressure drop across the system (a few inches W.C. when ESP's or fabric filters are used, and up to 100 inches W.C. if scrubbers are used). When the fan is located upstream of the control system, the volume of gas flow is large (because the gas is at high temperature). When the fan is located downstream of the control system, it does not have to handle such a large gas flow (because the gas is at low temperature); however, the control device must be of a heavier construction and reinforced because it must withstand high negative pressures. In either case, the fan must be insulated for protection against corrosion or constructed of corrosion-resistant materials. The duct work must also be well insulated.

The following section presents evaluations of different add-on control systems for application at the Magma Copper Company and Phelps Dodge Corporation smelters in question.

4.1 ADD-ON CONTROL SYSTEMS FOR MAGMA COPPER COMPANY, SAN MANUEL, ARIZONA

The reverberatory furnace flue gas is now treated in a hot ESP, which operates at 300°C (573°F) and has a design removal efficiency of 98 percent (measured by the ASTM in-stack methods). (This efficiency has never been verified by actual ASTM testing.) In EPA Method 5 sampling tests, the flue gas volume flow rate measured 18,264 m^3/min (645,000 acfm) at 300°C (573°F), and particulates averaged 1.76 g/m^3 (0.77 gr/scf) at 120°C (250°F), with a maximum of 2.9 g/m^3 (1.25 gr/scf) at the outlet of the ESP. The allowable particulate emission rate for the furnace is 18 kg/hr (39.7 lb/hr) or 0.032 g/m^3 (0.014 gr/scf). Thus, additional particulate matter control with an average efficiency of 98.18 percent (maximum 98.88 percent) is required for compliance. The three units of the hot ESP are situated in parallel (west to east), and the stack is located to the north. These units operate under negative pressure without a fan.

Enough space is available for add-on control equipment south of the existing SCRA* pilot plant. Evaluations of different add-on control for the Magma smelter reverberatory furnace are discussed in this section. Magma Copper Company is planning to convert the reverberatory furnaces from gas and oil firing to coal firing. The evaluations of add-on control systems in this section do not apply to conditions that will prevail after the reverberatory furnaces have been converted to coal.

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[*] Smelter ~~Coordinating~~ Control Research Association.

Add-on Fabric Filter Control System

Appendix B presents an add-on fabric filter control system specification for Magma Copper Company. Based on their best judgment, two IGCI members evaluated a system according to this specification. Table 4-1 presents the design parameters for these evaluations.

Evaluation A on this table involves a system designed to cool gases from the hot ESP to 120°C (250°F) in a spray cooling chamber, then to treat the gases in a fabric filter. Design and instrumentation of the spray chamber must be precise to keep the exit gas in dry condition. The chamber is a cocurrent spray tower made of carbon steel with a brick-lined bottom. The top of the chamber requires no lining. The gas transportation portion downstream of the chamber is properly lined to resist corrosion. Bag material is fiberglass to insure that no damage occurs if the cooling system fails. The baghouse external wall is constructed of insulated carbon steel.

Evaluation B involves a system designed to cool the hot ESP exit gas to 120°C (250°F) by the addition of dilution air and to treat the gas in a fabric filter system equipped with dacron bags. The dilution air cooling increases the volume of gas to be treated to about four times that of the original volume exiting the hot ESP. The bidder expressed his belief that although dilution air cooling greatly increases the size and cost of the collection equipment, it is technically superior to the spray chamber or the air-to-air heat exchanger. The inlet and outlet plenums and the plate compartment walls of the baghouse system are made of 3/16-in. A36 material. A mineral wool insulation 3 in. thick and aluminized steel logging are used in the baghouse.

The best solution for temperature control appears to be

Table 4-1. DESIGN PARAMETERS OF ADD-ON CONTROL FABRIC FILTER SYSTEM FOR MAGMA COPPER SMELTER.

Parameter	Evaluation A	Evaluation B
System description	Spray water cooling of gas to 120°C (250°F), fabric filter followed by a fan	Air dilution of gas to 120°C (250°F), fabric filter followed by a fan
Gas volume flow rate from the existing ESP to cooling system:		
Actual conditions	18,264 m^3/min (645,000 acfm)	18,264 m^3/min (645,000 acfm)
Standard conditions[a]	9,316 m^3/min (329,000 scfm)	9,316 m^3/min (329,000 scfm)
Temperature	300°C (573°F)	300°C (573°F)
Moisture content	8.7%	8.7%
Particulate loading:[a]		
Concentration	1.762 g/m^3 (0.77 gr/scf)	1.762 g/m^3 (0.77 gr/scf)
Weight rate	979 kg/hr (2158 lb/hr)	979 kg/hr (2158 lb/hr)
Type of cooling	Concurrent water spray cooling	Dilution air
Number of units	2	
Dimensions of each unit	6.1 m x 21.3 m (20 ft x 70 ft)	
Water consumption	61.32 m^3/hr (270 gpm)	
Dilution air		2652 m^3/min (936,500 scfm)
Fabric Filter System		
Total volume flow from cooling system to add-on fabric filter system:		
Actual conditions	13,400 m^3/min (474,640 acfm)	49,554 m^3/min (1,750,000 acfm)
Standard conditions	10,039 m^3/min (354,310 scfm)	36,990 m^3/min (1,306,000 scfm)
Temperature	120°C (250°F)	120°C (250°F)
Moisture content	21.1%	2.2%
Filter type	Fiber glass	Combination dacron
Air-to-cloth ratio (net)	2:1	1.49:1
Air-to-cloth ratio (gross)		1.37:1
No. of compartments (net)	34	38
No. of compartments (gross)		41
Cleaning mechanism	Reverse air	Shaker type
Fan: Location	Downstream of the system	Downstream of the system
Number	3	8
Pressure drop	2.985 kPa (12 in. W.C.)	2.737 kPa (11 in. W.C.)
Power required (total)	1100 kW (1475 HP)	4705.4 kW (6310 HP)

a combination of spray cooling and dilution cooling. Calculations show that cooling the gas to 204°C (400°F) by water evaporation, then to 120°C (250°F) by air dilution, would increase the gas volume to 23,530 m^3/min (831,000 acfm), which is only about 50 percent of that which would be produced by complete reliance upon air dilution cooling.

Add-on Fabric Filter Control System Costs

Tables 4-2 and 4-3 present a capital and annual operating cost breakdown for Evaluations A and B. These evaluations represent the cost of equipment as of the last quarter of 1977. Only basic equipment is included; no spares are represented in these costs. Duct costs are estimated on the basis of 110 m (360 ft) of duct from the existing ESP outlet to the inlet flange of the system, an appropriate length within the system, and a return duct of 107 m (350 ft) from the system outlet to the existing stack. Capital charges in the annual operating costs were calculated as 17.5 percent of total turnkey costs. This rate is based on a 10 percent interest rate, 15 years equipment life, and 4.3 percent for taxes and insurance.

The data show that an add-on fabric filter system to enable Magma Copper Company to comply with the applicable emission regulations will entail capital costs of $337.73 to $854.52 per m^3/min ($9.56 to $24.20 per acfm) of ESP exhaust gas, depending on the type of cooling system included and based on a gas flow rate of 18,264 m^3/min (645,000 acfm). System A, which contains a spray chamber for gas cooling and a fabric filter for particulate control, costs $337.73 per m^3/min ($9.56 per acfm) of gas introduced into the system. System B, which uses dilution air cooling for gas temperature reduction and a fabric filter for particulate control, costs $854.52 per m^3/min ($24.20 per acfm) of gas introduced into

Table 4-2. CAPITAL COST DATA FOR ADD-ON CONTROL FABRIC FILTER SYSTEM FOR MAGMA COPPER SMELTER.

Parameter	Evaluation A	Evaluation B
System description	Spray water cooling of gas to 120°C (250°F), fabric filter followed by a fan	Air dilution of gas to 120°C (250°F), fabric filter followed by a fan
Inlet gas flow:		
Actual conditions	13,440 m^3/min (474,640 acfm)	49,550 m^3/min (1,750,000 acfm)
Standard conditions	10,000 m^3/min (354,310 acfm)	36,980 m^3/min (1,306,000 acfm)
Temperature	120°C (250°F)	120°C (250°F)
Moisture content	21.1%	2.2%
Contaminant loading:		
Inlet, concentration	1.6 g/m^3 (0.716 gr/scf)	0.71 g/m^3 (0.310 gr/scf
Inlet, flow rate	989 kg/hr (2180 lb/hr)	1599 kg/hr (3524 lb/hr)
Outlet, concentration	0.028 g/m^3 (0.012 gr/scf)	0.0092 g/m^3 (0.004 gr/scf)
Outlet, flow rate	18.0 kg/hr (39.7 lb/hr)	18.0 kg/hr (39.7 lb/hr)
Cleaning efficiency, %	98.2	98.8
Gas cleaning equipment cost	$1,447,500	$6,200,000
Cost of auxiliaries:		
Fan w/drive	143,400	1,000,000
Screw conveyor/air lock	58,800	a
Cooling tower/accessories	263,100	
Total equipment cost	$1,912,800	$7,200,000
Installation costs, direct:		
Foundation and supports	$ 114,800	b
Duct work[c]	1,412,000	2,387,000
Stack	0	0
Piping	19,100	b
Insulation[d]	378,800	2,053,000
Painting	47,800	b
Electrical	210,400	b
Other	475,000	3,483,000
Total direct costs	$2,657,900	$ 7,923,000
Installation costs, indirect:		
Engineering	$ 187,500	d
Construction & field expenses	994,600	d
Construction fees	296,500	d
Start-up	25,500	$ 22,000
Performance test	17,000	30,000
Contingencies	76,500	432,000
Total indirect costs	$1,597,600	$ 484,000
Turnkey cost	$6,168,300	$15,607,000

[a] Included in gas cleaning equipment.
[b] Included in others.
[c] Includes material and labor, necessary insulation, and lining of duct.
[d] For gas cleaning equipment only.
[e] Included with direct cost.

Table 4-3. ANNUAL OPERATING COST DATA FOR ADD-ON FABRIC FILTER FOR MAGMA COPPER SMELTER.

Parameter	Evaluation A	Evaluation B
System description	Spray water cooling of gas to 120°C (250°F), fabric filter followed by a fan	Air dilution of gas to 120°C (250°F), fabric filter followed by a fan
Inlet gas flow:		
Actual conditions	13,440 m^3/min (474,640 acfm)	49,500 m^3/min (1,750,000 acfm)
Standard conditions	10,000 m^3/min (354,310 scfm)	36,980 m^3/min (1,306,000 scfm)
Temperature	120°C (250°F)	120°C (250°F
Moisture content	21.1%	2.2%
Contaminant loading:		
Inlet, concentration	1.6 g/m^3 (0.716 gr/scf)	0.71 g/m^3 (0.310 gr/scf)
Inlet, flow rate	989 kg/hr (2180 lb/hr)	1599 kg/hr (3524 lb/hr)
Outlet, concentration	0.028 g/m^3 (0.012 gr/scf)	0.0092 g/m^3 (0.004 gr/scf)
Outlet, flow rate	18.0 kg/hr (39.7 lb/hr)	18.0 kg/hr (39.7 lb/hr)
Cleaning efficiency		
Operating hours per year	8760	8760
DIRECT COSTS		
Operating labor:		
Operator, $10/man-hour	$43,800	$41,600
Supervisor, $12/man-hour	8,800	
Total	52,600	41,600
Maintenance:		
Labor, $10/man-hour	43,800	315,500
Materials	1,900	4,200
Total	45,700	319,700
Replacement parts	59,500	a
Utilities:		
Electricity, $0.03/kWh	473,700	1,375,000
Water, $0.25/1000 gal.	36,400	a
Compressed air, $0.02/1000 ft^3		500
Total	510,100	1,375,500
Total direct costs:	$667,900	$1,736,900
Capital charges	1,079,300	2,731,200
Total annual cost	$1,747,200	$4,468,000

[a] Included in maintenance labor.

the system. The respective gas cleaning equipment (including auxiliaries) costs are 31 percent of the total turnkey capital costs for Evaluation A and 46 percent for Evaluation B. Annual operating costs of particulate removal are \$0.21/kg (\$0.09/lb), or \$4787/day, for Evaluation A, and \$0.32/kg (\$0.15/lb), or \$12,241/day, for Evalulation B. Utility costs and capital charges represent about 91 percent of the total annual operating costs for Evaluation A and 92 percent for Evaluation B.

Add-on Wet Scrubber Control System

Appendix B contains a specification for an add-on wet scrubber system at the Magma Copper smelter. Based on this specification, three bidders used their best judgment to evaluate the scrubber system.

Although all three evaluations are based on the same specification, they are not comparable because the individual systems are designed for different pressure drops (ΔP) across the system. Pressure drop is a principal design parameter of a system, usually determined by particle size distribution and chemical analysis of the particulate matter. Because of a lack of sufficient data on these parameters, the bidders used their experience and judgment to determine pressure drop. Table 4.4 presents design parameters of these evaluations (C, D, and E).

In Evaluation C, ESP exhaust exit gas is treated in two identical scrubber units, each containing a quencher, an adjustable venturi, a flooded elbow, and a mist eliminator followed by two fans. Each unit treats half of the total volume flow, which is 9132 m^3/min (322,500 acfm). Estimated pressure drop for this system is 24.9 kPa (100 in. W.C.). The quencher is fabricated of carbon steel at least 1/2 in. thick. The inlet flow passage to the quencher, the outlet

Table 4-4. ADD-ON CONTROL SCRUBBER SYSTEM DESIGN PARAMETER FOR MAGMA COPPER SMELTER

Parameter	Evaluation C	Evaluation D	Evaluation E
System description	A prequencher, an adjustable venturi, a flooded elbow, and a mist eliminator separator followed by two fans	A fan, a separate quencher, and a venturi scrubber	A prequencher, a venturi, and a separator followed by a fan
Gas volume flow rate from the existing ESP to the system:			
Actual conditions	18,264 m^3/min (645,000 acfm)	18,264 m^3/min (645,000 acfm)	18,264 m^3/min (645,000 acfm)
Temperature	300°C (573°F)	300°C (573°F)	300°C (573°F)
Standard conditions	9260 m^3/min (327,000 scfm)	9260 m^3/min (327,000 scfm)	9260 m^3/min (327,000 scfm)
Moisture content	8.7%	8.7%	8.7%
Particulate loading:[a]			
Concentration	1.762 g/m^3 (0.77 gr/scf)	1.762 g/m^3 (0.77 gr/scf)	1.762 g/m^3 (0.77 gr/scf)
Weight rate	979 kg/hr (2158 lb/hr)	979 kg/hr (2158 lb/hr)	979 kg/hr (2158 lb/hr)
Number of units	2	2	1
Gas volume flow rate to quencher/prequencher in each unit:			
Actual conditions	9075 m^3/min (320,500 acfm)	9075 m^3/min (320,500 acfm)	9075 m^3/min (320,500 acfm)
Temperature	300°C (573°F)	300°C (573°F)	300°C (573°F)
Standard conditions	4630 m^3/min (163,500 scfm)	4630 m^3/min (163,500 scfm)	4630 m^3/min (163,500 scfm)
Quencher dimensions	3.2 m x 1.07 m (10.5 ft x 3.5 ft)	4.6 m x 11.6 m (15 ft x 38 ft)	5.03 m x 12.2 m (16.5 ft x 40 ft)
Evaporative water addition to	34.1 m^3/hr (150 gpm)	51.1 m^3/hr (225 gpm)	

Table 4-4 (continued).

Parameter	Evaluation C	Evaluation D	Evaluation E
Gas volume flow rate at scrubber exit in each unit:			
Actual conditions	9872 m^3/min (349,160 acfm)	6625 m^3/min (233,970 acfm)	11,950 m^3/min (421,900 acfm)
Temperature	52°C (125°F)	64°C (148°F)	60°C (140°F)
Standard conditions	10,800 m^3/min (382,220 scfm)	4660 m^3/min (164,500 scfm)	11,150 m^3/min (393,740 scfm)
Moisture content	12.94%	25.4%	
Particulate loading	0.032 g/m^3 (0.014 gr/acf)	0.032 g/m^3 (0.014 gr/acf)	0.032 g/m^3 (0.014 gr/scf)
Scrubber system clean efficiency	98.2%	99.0%	Minimum 98.2
Scrubbing water quantity (recycled)	35.77 m^3/min (9450 gpm)	6.18 m^3/min (1635 gpm)	11.34 m^3/min (3000 gpm)
Venturi scrubber rate	35.7 m^3/min (9430 gpm)	6.2 m^3/min (1640 gpm)	
Makeup water addition rate	1.19 m^3/min (314 gpm)[b]	1.92 m^3/min (503 gpm)[c]	1.02 m^3/min (280 gpm)
Total scrubber pressure drop	24.9 kPa (100 in. W.C.)	14.92 kPa (60 in. W.C.)	6.47 kPa (26 in. W.C.)
Scrubber dimensions	7.6 m x 10.7 m x 16m (25 ft x 35 ft x 53 ft)	5.9 m x 11.6 m (19 ft 6 in. x 38 ft 5 in.)	9.1 m x 18.2 m (30 ft x 60 ft)
Demister dimensions	3.4 m x 5.2 m x 0.6 m (11 ft x 17 ft x 2 ft)	5.9 m x 0.025 m (19 ft 6 in. x 1 in. high)	9.14 m dia. (30 ft dia.) 18.2 overall length (60 ft overall length
Fan location	Downstream of the scrubber	Upstream of the scrubber	Downstream of the system
Number of fans per unit	2	1	1
Estimated power required	2790 kW (3750 HP)	3251 kW (4360 HP)	2050 kW (2750 HP)

[a] Maximum particulate loading during furnace charging is 2.86 g/m^3 or 1584 kg/hr (1.25 gr/scf or 3504 lb/hr)

[b] 68.4 m^3/hr (303 gpm) water for evaporation into the gas in quencher and 2.3 m^3/hr (10.1 gpm) water to make up for that removed from the system for treatment.

[c] 101 m^3/hr (450 gpm) water for evaporation into the gas in quencher and 14.4 m^3/hr (63 gpm) water to make up for that removed from the system for treatment.

flow passage from the venturi to the flooded elbow, and the flooded elbow itself are all fabricated of carbon steel at least 1/2 in. thick, lined with Ceilcote. The venturi scrubber is fabricated of 1/2-in. thick Grade B or Grade C steel plate. The converging throat and diverging sections are lined with silicon carbide brick. The wetted parts of the fan are made of 316 L SS.

The system in Evaluation D contains two scrubber units, each with a fan and separate quencher followed by a venturi scrubber. This system operates at a pressure drop of 14.94 kPa (60 in. W.C.). The bidder believes this pressure drop and associated power requirements could be significantly lower, and that a pilot test should be conducted to determine actual pressure drop. The preconditioner is constructed of mild steel with a Gunite or Savereisin acid-resistant cement lining. Flow velocities are low to reduce abrasive wear. The scrubber would be constructed of 316 L stainless steel unless the scrubbing water is high in chlorides.

The one-unit scrubber system in Evaluation E consists of a prequench section, a venturi, and a separator section followed by a fan. The pressure drop of this system is 6.47 kPa (26 in. W.C.). The bidder indicated that some study has been made regarding the scrubbing of reverberatory furnace gases in copper smelters; and, based on limited scrubbing pilot plant data, he believes that a pressure drop of 6.47 kPa (26 in. W.C.) is a reasonable choice to produce 96 to 98 percent efficiency by weight. The general material of construction is acid-brick-lined steel; the hot gas zones and high-velocity sections of the scrubbers are constructed of FRP-lined steel. All alloy parts in the venturi are of Inconel 625. The fan wheel and shaft will be supplied in Incoloy-825 or 904L material. Inlet ducting is a 1/4-in. and 3/8-in. carbon steel with exterior weatherproof insulation. The material of construction for the prequencher and venturi is 1/4-in. and 3/8-in. carbon steel with 60- to 80-mil flaked-glass lining plus 3-in. acid brick and foam glass interior lining. Alloy parts are of Inconel 625. The separator is 1/4-in., 3/8-in. and 1/2-in. carbon steel with 60- to 80-mil flaked glass lining. The base of the separator mill is lined with 3-in. acid brick up to 2 ft. above gas inlet. The exit ducting to the fan and stack is of 5/8-in.-thick FRP-Hetron 197 with flame retardant.

Carbon steel is the material of construction for the water treatment systems in all evaluations.

Based on these evaluations, it is apparent that pilot plant tests are necessary to produce a wet scrubber with the desired efficiency.

Add-on Wet Scrubber Control System Costs

Tables 4.5 and 4.6 present capital and annual operating costs for the three systems. These evaluations represent the cost of equipment during the last quarter of 1977. They include only basic equipment (no spare equipment). The following parameters were used in the duct cost estimate: a duct length of 110 m (360 ft) from the existing ESP exit to the add-on control system inlet, an appropriate duct length within the system, and a return duct of 107 m (350 ft) from the add-on system outlet to the existing stack. Capital charges in the annual operating costs were calculated by using 20.5 percent of the total turnkey cost. This rate is based on an interest rate of 10 percent, an equipment life of 10 years, and a tax and insurance rate of 4.22 percent.

Data show that the turnkey capital cost of an add-on scrubber system ranges from \$218 to 279 per actual cubic meter/min (\$6.18 to 7.89 per acfm) of gas entering the system. The individual turnkey capital cost estimates are \$264.13, \$218.24, and \$278.69 per actual cubic meter/min

Table 4-5. CAPITAL COST DATA FOR ADD-ON CONTROL SCRUBBER SYSTEM FOR MAGMA COPPER SMELTER

Parameter	Evaluation C	Evaluation D	Evaluation E
System description	A prequencher, an adjustable venturi, a flooded elbow, and a mist eliminator separator followed by two fans	A fan, a separate quencher, and a venturi scrubber	A prequencher, a venturi, and a separator followed by a fan
Gas flow at scrubber outlet:			
Actual conditions	19,744 m^3/min (698,330 acfm)	13,250 m^3/min (467,941 acfm)	11,950 m^3/min (421,900 acfm)
Temperature	51.6°C (125°F)	64°C (148°F)	54.4°C (130°F)
Standard conditions	10,800 m^3/min (382,220 scfm)	9320 m^3/min (329,000 scfm)	10,050 m^3/min (354, 780 scfm)
Moisture content	12.44%	Saturated	
Contaminant loading:[a]			
Inlet	1.76 g/m^3 (.77 gr/scf)	1.76 g/m^3 (.77 gr/scf)	1.76 g/m^3 (0.77 gr/scf)
Inlet	984.31 kg/hr (2170 lb/hr)	984.31 kg/hr (2170 lb/hr)	984.31 kg/hr (2170 lb/hr)
Outlet	0.032 g/m^3 (0.014 gr/scf)	0.032 g/m^3 (0.014 gr/scf)	0.032 g/m^3 (0.014 gr/scf)
Outlet	18.01 kg/hr (39.7 lb/hr)	18.01 kg/hr (39.7 lb/hr)	18.01 kg/hr (39.7 lb/hr)
Cleaning efficiency	98.2%	98.2%	98.2%
Gas cleaning equipment cost[b]	$506,000	$273,600	$1,000,000
Cost of auxiliaries:			
Fan with drive	$1,183,000	$661,400	$340,000
Pumps	20,000	29,000	50,000
Tanks	c	118,000	20,000
Water treatment[d]	126,000	121,300	150,000
Others	89,000[e]	75,700	

Table 4-5 (continued).

Parameter	Evaluation C	Evaluation D	Evaluation E
Total equipment cost	$1,924,000	$1,279,000	$1,560,000
Installation costs, direct:			
Foundation and supports	$ 106,300	$ 90,000	
Duct work[f]	2,000,000	2,402,000	1,737,000
Stack	0	0	
Piping		65,000	
Insulation[g]	75,000	25,000	
Painting	12,100	12,800	
Electrical	7,600	36,200	
Other	172,900		
Total direct costs	$2,373,900	$2,631,000	$1,793,000[h]
Installation cost, indirect:			
Engineering	$ 35,400	$ 22,000	
Construc. & fields expenses	374,400	20,000	
Construction fees	5,100	5,000	
Start-up	25,300	7,000	
Performance test	35,400	12,000	
Contingencies	50,600	10,000	
Total indirect costs	526,200	76,000	
Turnkey cost	$4,824,100	$3,986,000	$5,090,000

[a] Particulate content of the gas at the inlet and outlet is based on the gas flow rate of 9260 m^3/min (327,000 scfm) to the system.

[b] Includes preconditioning equipment (quencher), scrubber, and associated tanks.

[c] Included in the gas cleaning equipment cost.

[d] Materials and labor.

[e] Piping and instrumentation.

[f] Includes material and labor, and necessary insulation and lining of duct.

[g] For gas cleaning equipment.

[h] Includes total of direct costs and indirect costs, excluding foundation and duct costs.

Table 4-6. ANNUAL OPERATING COST DATA FOR ADD-ON CONTROL SCRUBBER FOR MAGMA COPPER SMELTER

Parameter	Evaluation C	Evaluation D	Evaluation E
System description	A prequencher, and adjustable venturi, a flooded elbow, and a mist eliminator separator followed by two fans	A fan, a separate quencher, and a venturi scrubber	A prequencher, a venturi, and a separator followed by a fan
Gas flow at scrubber outlet:			
Actual conditions	19,744 m^3/min (698,330 acfm)	13.250 m^3/min (467,941 acfm)	11,950 m^3/min (421,900 acfm)
Temperature	51.6°C (125°F)	64°C (148°F)	54.4°C (130°F)
Standard conditions	10,800 m^3/min (382,220 scfm)	9320 m^3/min (329,000 scfm)	10,050 m^3/min (354,780 scfm)
Moisture content	12.44%	Saturated	
Contaminant loading:[a]			
Inlet	1.76 g/m^3 (0.77 gr/scf)	1.76 g/m^3 (0.77 gr/scf)	1.76 g/m^3 0.77 gr/scf)
Inlet[a]	984.31 kg/hr (2170 lb/hr)	984.31 kg/hr (2170 lb/hr)	984.31 kg/hr (2170 lb/hr)
Outlet	0.016 g/m^3 (0.014 gr/scf)	0.018 g/m^3 (0.014 gr/scf)	0.032 g/m^3 (0.014 gr/scf)
Outlet[a]	18.01 kg/hr (39.7 lb/hr)	18.01 kg/hr (39.7 lb/hr)	18.01 kg/hr (39.7 lb/hr)
Cleaning efficiency	98.2%	98.2%	98.2%
Operating hours per year	8760	8760	8760
DIRECT COSTS			
Operating labor:			
Operator, $10/man-hour	$122,200	$87,600	$27,100
Supervisor, $12/man-hour	37,000	24,000	9,700
Total	159,200	111,600	36,800

Table 4-6 (continued).

Parameter	Evaluation C	Evaluation D	Evaluation E
Maintenance:			
Labor, $10/man-hour	59,200	3,600	27,100
Materials	41,000	3,000	18,500
Total	100,200	6,600	45,600
Replacement parts	26,000	20,000	18,500
Utilities:			
Electricity, $0.01/kWh	3,136,000	1,744,100	479,800
Water	31,500	53,900	29,400
Chemical water treatment	24,200	9,500	31,800
Total direct cost	$3,477,100	$1,945,700	$641,940
Capital charges	989,000	817,100	1,043,600
Total annual cost	$4,466,100	$2,762,800	$1,685,500

[a] Particulate content of the gas at the scrubber inlet and outlet is based on the gas flow rate 9260 m^3/min (327,000 scfm) to the system.

($7.48, $6.18, and $7.89 per acfm) of gas entering the system for Evaluations C, D, and E respectively. Gas flow rate to each system is 18,264 m^3/min (645,000 acfm). Cost of gas cleaning equipment, including auxiliaries, varies from 30 to 40 percent of the total turnkey cost. The respective annual operating costs for the three systems are $0.53, and $0.33, and $0.20/kg ($0.24, $0.15, and $0.09/lb) of particulate removed, or $12,236, $7,569, and $4,618 per day. Utilities and capital charges represent 71 percent and 22 percent in Evaluation C, 65 percent and 29 percent in Evaluation D, and 32 percent and 62 percent in Evaluation E.

Add-on Dry ESP Control System

Appendix B contains specifications for an add-on dry ESP for the Magma Copper Smelter. Using their best judgment, three members of IGCI evaluated the requirements based on information given to them. Table 4-7 presents design parameters of the add-on dry ESP system.

Evaluations F, G, and H all involve two parrallel systems, each containing a fan, a cooling system, and an ESP. The fan is placed on the hot side of the cooling system to avoid a potential corrosion and imbalance problem. Design and instrumentation of the cooling system must be precise to keep the exit gas dry. A pilot study of the ESP is recommended to assess the corrosive and sticky nature of the dust.

Add-on Dry ESP Control System Costs

Tables 4-8 and 4-9 present capital and annual operating cost breakdowns for Evaluations F, G, and H. The evaluations represent the cost of equipment during the last quarter of 1977. They include only basic equipment (no spare equipment). Duct costs in the three estimates are based on 110 m (360 ft) of duct from the existing ESP outlet to the inlet of the add-on control system, an appropriate length within the

Table 4-7. DESIGN PARAMETERS OF ADD-ON DRY ELECTROSTATIC PRECIPITATOR SYSTEM FOR MAGMA COPPER SMELTER

Parameter	Evaluation F	Evaluation G	Evaluation H
System description	A fan, evaporative cooling to 120°C (250°F), a dry electrostatic precipitator	A fan, an evaporative cooling tower, followed by dry electrostatic precipitator	A fan, concurrent flow cooling tower to 120°C (250°F), a dry electrostatic precipitator
Gas volume flow rate from the existing electrostatic precipitator to cooling system:			
Under actual conditions	18,264 m^3/min (645,000 acfm)	18,264 m^3/min (645,000 acfm)	18,264 m^3/min (645,000 acfm)
Under standard conditions	9316 m^3/min (329,000 acfm)	9316 m^3/min (329,000 acfm)	9316 m^3/min (329,000 acfm)
Temperature	300°C (575°F)	300°C (573°F)	300°C (573°F)
Moisture content, percent	8.7%	8.7%	8.7%
Type of cooling	Evaporative cooling	Evaporative cooling	Evaporative cooling
Number of units	2	2	2
Dimensions of each unit		8.99 m dia x 25.5 m length (29.5 ft dia x 83.6 ft length)	
Water consumption	34.1 m^3/hr (150 gpm)	25 m^3/hr (110 gpm)	34.1 m^3/hr (150 gpm)
Total volume flow rate from cooling systems to add-on electrostatic precipitator:			
Under actual conditions	14,470 m^3/min (511,000 acfm)	14,040 m^3/min (495,830 acfm)	13,567 m^3/min (479,106 acfm)
Under standard conditions	10,801 m^3/min (381,450 acfm)	10,481 m^3/min (370,137 acfm)	9401 m^3/min (332,000 acfm)
Temperature	120°C (250°F)	120°C (250°F)	120°C (250°F)
Number of ESP's	2	2	2
Dimension of each	19.8 m x 15.8 m x 15.5 m (65 ft x 52 ft x 51 ft)[a]	26.5 m L x 14.83 m W (87.1 ft L x 48.7 ft W)	
Number of chambers per ESP	2	1	1
Number of fields	5[b]	5[b]	3
Number of passages per chamber	31	48	44
Length of each field	2.74 m (9.0 ft)	3.81 m (12.5 ft)	3.24 m (10.625 ft)
Field height	9.1 m (30 ft)	9.40 m (30.83 ft)	10.97 m (36 ft)
Number of energizing means	10	10	
Current	1500 mA	1250 mA	3327 mA
Voltage	70 kV	56 kV	45 kV
Wave form	Full	Full	Full
Migration velocity	3.96 cm/s (0.13 ft/s)	3.41 cm/s (0.112 ft/s)	4.84 cm/s (0.158 ft/s)
Specific collecting area, net	103.2 m^2 per m^3/s (524 ft^2/1000 acfm)[c]	118 m^2 per m^3/s (597 ft^2/1000 acfm)[d]	82.9 m^2 per m^3/s (421 ft^2/1000 acfm)
Total power consumption (ESP)	1400 kW (1870 HP)	1995 kW (2665 HP)	1100 kW (1475 HP)
Fan: location	Hot side of cooling system	Hot side of cooling system	Hot side of cooling system
Number	2	2	2
Pressure drop	0.995 kPa (4 in. W.C.)	1.99 kPa (8 in. W.C.)	1.791 kPa (7.2 in. W.C.)
Power required	448 kW (600 HP)	429 kW (575 HP)	448 kW (600 HP)

[a] Excluding nozzles.

[b] One field is redundant.

[c] 129 m^2 per m^3/s (655 ft^2/1000 acfm) gross.

[d] 146.5 m^2 per m^3/s (746 ft^2/1000 acfm) gross.

Table 4-8. CAPITAL COST DATA FOR ADD-ON DRY ELECTROSTATIC PRECIPITATOR SYSTEM FOR MAGMA COPPER SMELTER

Parameter	Evaluation F	Evaluation G	Evaluation H
System description	A fan, evaporative cooling to 120°C (250°F), a dry electrostatic precipitator	A fan, an evaporative cooling to 120°C (250°F), followed by a dry electrostatic precipitator	A fan, evaporative cooling tower to 120°C (250°F), a dry electrostatic precipitator
Inlet gas flow:			
Actual conditions	14,470 m^3/min (511,000 acfm)	14,040 m^3/min (495,830 acfm)	13,567 m^3/min (479,106 acfm)
Standard conditions	10,801 m^3/min (381,450 acfm)	10,481 m^3/min (370,137 acfm)	9401 m^3/min (332,000 acfm)
Temperature	102°C (250°F)	120°C (250°F)	120°C (250°F)
Contaminant loading:[a]			
Inlet, concentration	1.76 g/m^3 (0.77 gr/acf)	1.76 g/m^3 (0.77 gr/acf)	1.76 g/m^3 (0.77 gr/acf)
Inlet, wt. rate	984.31 kg/hr (2170 lb/hr)	984.31 kg/hr (2170 lb/hr)	984.31 kg/hr (2170 lb/hr)
Outlet, concentration	0.032 g/m^3 (0.014 gr/acf)	0.032 g/m^3 (0.014 gr/acf)	0.032 g/m^3 (0.014 gr/acf)
Outlet, wt. rate	18.01 kg/hr (39.7 lb/hr)	18.01 kg/hr (39.7 lb/hr)	18.01 kg/hr (39.7 lb/hr)
Cleaning efficiency	98.2%	98.2%	98.2%
Gas cleaning equipment cost	$1,688,000	$1,960,000	$2,053,000
Cost of auxiliaries:			
Fan with drive	223,000	300,000	271,400
Evaporative cooling tower	683,000	863,000	683,000
Others	384,000[b]	300,000[c]	211,600[d]
Total equipment cost	$2,978,000	$3,423,000	$3,219,000
Installation costs, direct:			
Foundation and supports (M&L)[e]	$ 293,000	$ 216,000	$ 81,200
Duct work[f]	1,504,000	1,513,800	1,497,000
Stack	0	0	0
Piping	Not quoted	Not quoted	Not quoted
Insulation	0	0	0
Painting	Not quoted	Not quoted	336,000
Electrical (material & labor)	Not quoted	637,400	Not quoted
Other	1,570,500[g]	1,629,000[h]	1,792,000[i]
Total direct costs	$3,367,500	$3,996,200	$3,706,200
Installation costs, indirect:			
Engineering	j	$ 308,000	k
Constr. and field expenses	j	235,000	$ 132,000
Construction fees	j	84,000	
Start-up	$ 25,000	25,000	11,800
Performance test	l	15,000	51,600
Model study	15,000	50,000	
Contingencies	280,000	305,000	258,300
Total indirect costs	$ 320,000	$1,022,000	$ 453,700
Turnkey cost	[illegible],665,500	$8,441,200	$7,378,900

[a] Particulate content of the gas at the inlet and outlet is based on a gas flow rate of 9260 m^3/min (327,000 acfm) to the system.

[b] Includes screw conveyors, slide gates, and louver dampers.

[c] Access and dust disposal.

[d] Slide gates and dampers.

[e] Includes only material and labor for precipitator supports.

[f] Includes material and labor, insulation, and lining.

[g] Includes cost of erection labor for total gas cleaning equipment, direct costs of electrical arrangements, and indirect costs connected with engineering and construction.

[h] Installation labor for gas cleaning equipment and auxiliaries.

[i] About 92.5 percent for installation of total gas cleaning equipment and remaining for freight on equipment.

[j] Included in others.

[k] Included in equipment cost.

[l] Included in cost of start-up.

Table 4-9. ANNUAL OPERATING COST DATA FOR ADD-ON CONTROL DRY ELECTROSTATIC PRECIPITATOR FOR MAGMA COPPER SMELTER

Parameter	Evaluation F	Evaluation G	Evaluation H
System description	A fan, evaporative cooling to 120°C (250°F), a dry electrostatic precipitator	A fan, an evaporative cooling tower, followed by dry electrostatic precipitator	A fan, concurrent flow cooling tower to 120°C (250°F) a dry electrostatic precipitator
Inlet gas flow			
Actual conditions	14,470 m^3/min (511,000 acfm)	14,040 m^3/min (495,830 acfm)	13,567 m^3/min (479,106 acfm)
Standard conditions	10,801 m^3/min (381,450 scfm)	10,481 m^3/min (370,137 scfm)	9401 m^3/min (332,000 scfm)
Temperature	120°C (250°F)	120°C (250°F)	120°C (250°F)
Contaminant loading[a]			
Inlet, concentration	1.76 g/m^3 (0.77 gr/scf)	1.76 g/m^3 (0.77 gr/scf)	1.76 g/m^3 (0.77 gr/scf)
Inlet, wt. rate	984.31 kg/hr (2170 lb/hr)	984.31 kg/hr (2170 lb/hr)	984.31 kg/h (2170 lb/hr)
Outlet, concentration	0.032 g/m^3 (0.014 gr/scf)	0.032 g/m^3 (0.014 gr/scf)	0.032 g/m^3 (0.014 gr/scf)
Outlet, wt. rate	18.01 kg/hr (39.7 lb/hr)	18.01 kg/hr (39.7 lb/hr)	18.01 kg/hr (39.7 lb/hr)
Cleaning efficiency	98.2%	98.2%	98.2%
Operating hours per year	8760	8760	8760
DIRECT COSTS			
Operating labor			
Operator, $10/man-hour	$21,500	$32,000	$11,000
Supervisor, $21/man-hour	4,400	4,500	4,500
Total	25,900	36,500	15,500
Maintenance			
Labor, $10/man-hour	11,000	12,600	8,000
Materials	7,800	7,800	4,500
Total	18,800	20,400	12,500
Replacement part[b]	5,200	b	4,500
Utilities			
Electricity, $0.03/kWh	367,900	524,300	290,000
Water, $0.25/1000 gal	19,700	14,500	19,700
Total	387,600	538,800	309,700
Total direct costs	437,500	595,700	342,200
Capital charges	$1,166,500	$1,477,200	$1,291,300
Total annual cost	$1,604,000	$2,072,900	$1,633,500

[a] Particulate content of the gas at the inlet and outlet is based on a gas flow rate of 9260 m^3/min (327,000 acfm) to the system.

[b] Included in maintenance.

system, and a return duct of 107 m (350 ft) from the system outlet to the existing stack. Capital charges in the annual operating costs were calculated by using 17.5 percent of the total turnkey costs. This rate is based on a 10 percent interest rate, 15 years of equipment life, and a rate of 4.35 percent for taxes and insurance.

The data show the use of an add-on dry ESP system to enable Magma Copper Company to comply with the applicable emission regulation will entail capital costs of \$365 to \$462 per m^3/min (\$10.00 to \$13.00 per acfm) based on existing ESP exhaust gas flow rate of 18,264 m^3/min (645,000 acfm). The respective turnkey capital costs are \$365 per m^3/min (\$10.33 per acfm) for Evaluation F, \$462 per m^3/min (\$13.00 per acfm) for Evaluation G, and \$404 per m^3/min (\$11.44 per acfm) for Evaluation H. The respective gas cleaning equipment costs are 45 percent of the total turnkey capital costs for Evaluation F, 41 percent for Evaluation G, and 44 percent for Evaluation H. Annual operating costs of particulate removal are \$0.19/kg (\$0.09/lb), or \$4480/day, for Evaluation F and Evaluation H, and \$0.25/kg (\$0.11/lb), or \$5679/day, for Evaluation G. Utility costs and capital charges represent about 97 percent of the total annual operating costs for Evaluation F and Evaluation G, and 98 percent for Evaluation H.

Add-on Wet Electrostatic Precipitator (WEP) Control System

Appendix B contains specifications for an add-on wet ESP at the Magma Copper smelter. Table 4-10 presents the design parameters of one WEP system (Evaluation I). The system involves a WEP designed to cool gases from the existing ESP in an evaporative cooling tower to 120°C (250°F), then to treat the gases in a WEP. The evaluation involves two parallel systems consisting of a fan, an evaporative

Table 4-10. ADD-ON CONTROL WET ELECTROSTATIC PRECIPITATOR SYSTEM DESIGN PARAMETERS FOR MAGMA COPPER SMELTER

Parameter	Evaluation I
System description	Two units each consists of a fan, an evaporative cooling tower, and a wet electrostatic precipitator
Gas volume flow rate from the existing electrostatic precipitator to system:	
Actual conditions	18,151 m^3/min (641,000 acfm)
Standard conditions	9313 m^3/min (328,877 scfm)
Temperature	300°C (573°F)
Moisture content	8.7%
Cooling system: type	Evaporative cooling tower
Number of units	2
Dimensions of each unit	8.99 m x 25.98 m (29.5 ft x 83.6 ft)
Liquid- to-gas ratio, L/G	0.0974 m^3 per m^3/min (355 gal/1000 acfm)
Electrostatic precipitator system	
Total volume flow rate at add-on precipitator system inlet or at gas cooling system outlet:	
Actual conditions	14,040 m^3/min (495,830 acfm)
Standard conditions	10,480 m^3/min (370,137 scfm)
Temperature	120°C (250°F)
Number of ESP's	2
Number of chambers per ESP	1
Number of fields per ESP	4[a]
Number of passages per chamber	31
Length of each field	3.33 m (10.92 ft)
Field height	9.40 m (30.83 ft)
Number of energizing means	4
Current	200 mA
Voltage	55 kV
Wave form	Full
Migration velocity	0.079 m/s (0.262 ft/s)
Spray water	5686 m^3/min (1502 gpm)
Flush water for inlet transition	1567 m^3/min (414 gpm)
Flush water for ESP plates[a]	15,490 m^3/min (4092 gpm)
Specific collecting area	49.6 m^2 per m^3/s (253 ft^2/1000 acfm)
Fan: Location	Hot-side cooling tower
Number	2
Pressure drop	1.99 kPa (8 in. W.C.)
Power required	429 kW (575 HP)

[a] One field is redundant.

cooling tower, and a WEP. The fan is located upstream of the cooling system to prevent a potential corrosion problem. The WEP is generally chosen when the particulate tends to be sticky and does not drop when the plates of a dry ESP are rapped. The WEP is a continuously sprayed, horizontal flow, parallel plate, and rigid frame discharge electrodes type. Water from a precisely designed water nozzle arrangement is sprayed at the WEP entrance to maintain a low resistivity of the particles entering into the system. Water sprays located above the electrostatic field sections introduce evenly distributed water droplets to the gas stream for washing all internal surfaces. The particulates and water droplets in the electrostatic fields pick up charges and migrate to the collecting plates. The plates are continuously flushed to remove the collected material into the troughs below which are sloped to a drain. The WEP parts not sprayed or flushed with water are constructed of corrosion-resistant materials. (The portion close to outlet of WEP is not sprayed or flushed with water in order to remove the carryover liquid drops and mists before the outlet of the equipment). The condensible material collected in the drain liquor can be separated by means of any sludge removal methods.

Cost of Add-on Wet Electrostatic Precipitator System

Tables 4-11 and 4-12 present capital and annual operating cost breakdowns for evaluation I. The evaluation represents the cost of equipment during the last quarter of 1977. It includes only basic equipment (no spares). Duct costs in all three evaluations are based on 110 m (360 ft) of duct from the existing ESP outlet to the inlet flange of the gas cooler, an appropriate length within the system, and a return duct of 107 m (350 ft) from the system flange to

Table 4-11. CAPITAL COST DATA FOR ADD-ON WET ELECTROSTATIC PRECIPITATOR SYSTEM FOR MAGMA COPPER SMELTER

Parameter	Evaluation I
System description	Two units. Each consists of a fan, an evaporative cooling tower, and a wet precipitator
Inlet gas flow:	
Actual conditions	14,010 m^3/min (495,830 acfm)
Standard conditions	10,481 m^3/min (370,137 scfm)
Temperature	120°C (250°F)
Contaminant loading:[a]	
Inlet, concentration	1.76 g/m^3 (0.77 gr/scf)
Inlet, wt. rate	984.31 kg/hr (2170 lb/hr)
Outlet, concentration	0.032 g/m^3 (0.014 gr/scf)
Outlet, wt. rate	18.01 kg/hr (39.7 lb/hr)
Cleaning efficiency	98.2%
Gas cleaning equipment cost	$1,284,000
Cost of auxiliaries:	
Fan with drive	300,000
Evaporative cooling tower	863,000
Water treatment[b]	
Others	83,000
Total equipment cost	$2,530,000
Installation costs, direct:	
Foundation and supports[b]	$ 103,500
Duct work[c]	1,455,900
Stack	0
Piping	
Insulation	650,000
Painting	
Electrical[c]	206,000
Other[d]	1,162,000
Total direct costs	$3,577,400
Installation costs, indirect:	
Engineering	$ 327,000
Construction and field expenses	160,000
Construction fees	60,000
Start-up	25,000
Performance test	15,000
Model study	50,000
Contingencies	246,000
Total indirect costs	$ 883,000
Turnkey cost	$6,990,400

[a] Particulate content of the gas at the inlet and outlet is based on a gas flow rate of 9260 m^3/min (327,000 scfm) to the system.

[b] Includes only material and labor for precipitator supports.

[c] Includes material and labor and necessary insulation and lining.

[d] Installation costs for gas cleaning equipment, auxiliaries, fan, and cooling tower.

Table 4-12. ANNUAL OPERATING COST DATA FOR ADD-ON WET ELECTROSTATIC PRECIPITATOR FOR MAGMA COPPER SMELTER

Parameter	Evaluation I
System description	Two units. Each consists of a fan, an evaporative cooling tower, and a wet electrostatic precipitator
Inlet gas flow:	
Actual conditions	14,040 m^3/min (495,830 acfm)
Standard conditions	10,481 m^3/min (370,137 scfm)
Temperature	120°C (250°F)
Contaminant loading:[a]	--
Inlet, concentration	1.76 g/m^3 (0.77 gr/scf)
Inlet, wt. rate	984.31 kg/hr (2170 lb/hr)
Outlet, concentration	0.032 g/m^3 (0.014 gr/scf)
Outlet, wt. rate	18.01 kg/hr (39.7 lb/hr)
Cleaning efficiency	98.2%
Operating hours per year	8760
DIRECT COSTS	
Operating labor:	
Operator, $10/man-hour	$ 21,400
Supervisor, $12/man-hour	3,000
Total	24,400
Maintenance:	
Labor, $10/man-hour	8,400
Materials	5,200
Total	13,600
Replacement parts	b
Utilities:	
Electricity, $0.03/kWh	414,800
Water, $0.25/1000 gal	471,000
Chemicals	
Total	885,800
Total direct costs:	$ 923,800
Capital charges	1,223,300
Total annual cost	$2,147,100

[a] Particulate content of the gas at the inlet and outlet is based on a gas flow rate of 9260 m^3/min (327,000 scfm) to the system.

[b] Included in maintenance.

existing stack flange. Capital charges in the annual operating costs were calculated by using 17.5 percent of the total turnkey costs. This rate is based on 10 percent interest, 15 years of equipment life, and 4.35 percent for taxes and insurance.

The data show that the use of an add-on WEP system (Evaluation I) by Magma Cooper Company to comply with the applicable emission regulation entails a capital cost of \$382.74 per m^3/ min (\$10.84 per acfm) of ESP exhaust gas (based on a gas flow rate of 18,264 m^3/min (645,000 acfm). This system uses an evaporative cooling system to cool the gas to 120°C (250°F) before it enters the WEP. Cost of gas cleaning equipment (including auxiliaries) is 36 percent of the total turnkey capital cost. Annual operating costs of particulate removal are \$0.25/kg (\$0.12/lb) or \$5883 per day. The utility costs and capital charges are about 41 percent and 57 percent of the total annual operating costs, respectively.

4.2 ADD-ON CONTROL SYSTEMS FOR PHELPS DODGE CORPORATION, AJO, ARIZONA

The reverberatory furnace flue gas is treated in a hot ESP consisting of two independent, parallel units (north of the furnace) followed by a fan and stack. The ESP operates at about 316°C (600°F) with a design removal efficiency of 96.83 percent (measured by ASTM instack method). The efficiency was tested and verified by Southern Research Institute and Radian Corporation in July 1976. EPA Method 5 sampling tests at the existing ESP exit measured a flue gas volume flow rate of 5270 m^3/min (186,000 acfm) at 314°C (598°F), average dust particulate loadings of 1.28 g/m^3 (0.56 gr/scf) at 120°C (250°F), and maximum particulate loadings of 3.14 g/m^3 (1.37 gr/scf). Mass emissions averaged 203 kg/hr (447 lb/hr) at 120°C (250°F); the maximum was 496 kg/hr (1094 lb/hr). Compliance with particulate regulations require an additional control of 93.0 percent efficiency during normal operation and 97.15 percent during furnace charging.

Enough space is available for an add-on control system north of the existing ESP. Water availability is supposedly limited. Evaluations of different add-on control for the Ajo smelter reverberatory furnace are discussed in this section.

Add-on Fabric Filter Control System

Appendix C presents the specification for a fabric filter add-on control system at the Phelps Dodge Corporation smelter. Three IGCI members used their best judgment to evaluate a system based on this specification. Table 4-13 presents design parameters of the systems evaluated.

Evaluation J is for a system consisting of a spray tower to cool gases from the existing hot ESP to 120°C (250°F), followed by a fabric filter for particulate control. The chamber is a cocurrent spray tower made of carbon steel with a brick-lined bottom. The gas transportation system (i.e., ductwork, fans and control devices) downstream of the chamber is properly lined to resist corrosion. Fabric filter bags are fiberglass to insure that no damage occurs if the cooling system fails.

Evaluation K involves a system designed to cool the hot ESP exit gas to 120°C (250°F) by adding dilution air, then treating the gas in a fabric filter system containing dacron bags. Dilution cooling increases the original gas volume of 5670 m^3/min (186,000 acfm) to 14,000 m^3/min (495,000 acfm). The bidder expressed his belief that although dilution air cooling greatly increases the size and cost of the collection equipment, it is technically superior to the tower and air-to-air heat exchanger. The inlet and outlet plenums and

Table 4-13. DESIGN PARAMETERS OF AN ADD-ON FABRIC FILTER SYSTEM FOR THE PHELPS DODGE CORPORATION SMELTER IN AJO, ARIZONA

Parameter	Control system	
	Evaluation J	Evaluation K
System description	Spray water cooling of gas to 120°C (250°F), a fabric filter, followed by a fan	Dilution air cooling of gas to 120°C (250°F), a fabric filter, followed by a fan
Gas volume flow rate from the existing electrostatic precipitator to cooling system:		
Actual conditions	5270 m^3/min (186,000 acfm)	5270 m^3/min (186,000 acfm)
Standard conditions[a]	2639 m^3/min (93,176 scfm)	2639 m^3/min (93,176 scfm)
Temperature	314°C (598°F)	314°C (598°F)
Moisture content	12.3%	12.3%
Particulate loading:		
Concentration	1.28 g/m^3 (0.56 gr/scf)	1.28 g/m^3 (0.56 gr/scf)
Weight rate	202.85 kg/hr (447.2 lb/hr)	202.85 kg/hr (447.2 lb/hr)
Type of cooling	Concurrent waterspray cooler	Dilution air
Number of units	1	
Dimension of each	7.01 m (23 ft) diameter 24.9 m (82 ft) overall height	
Water consumption	0.31 m^3/min (82 gpm)	
Dilution air		

Table 4-13 (continued).

Parameter	Evaluation J	Control system Evaluation K
Total volume flow rate from cooling system exit to add-on fabric filter system:		
Actual conditions	3700 m^3/min (130,690 acfm)	14,000 m^3/min (495,000 acfm)
Standard conditions[a]	2763 m^3/min (97,558 scfm)	10,460 m^3/min (369,500 scfm)
Temperature	120°C (250°F)	120°C (250°F)
Moisture content	25.3%	3.0%
Filter type	Fiberglass	Combination dacron
Air-to-cloth ratio (net)	2:1	1.60:1
Air-to-cloth ratio (gross)		1.46:1
No. of compartments (net)	10	10
No. of compartments (gross)		11
Pressure drop across the system		
Cleaning mechanism	Reverse air	Shaker type
Fan:	Downstream of the system	Downstream of the system
Location	1	3
Number	2.99 kPa (12 in W.C.)	2.74 kPa (11 in. W.C.)
Pressure drop	298 kW (400 hp)	1175 kW (1575 hp)

[a] Standard conditions are 101.3 kPa (14.7 psia) and 21°C (70°F).

the plate compartment walls are of 3/16 in. A36 material. A 3-in.-thick mineral wool insulation and aluminized steel lagging are used for baghouse.

Add-on Fabric Filter Control System Cost

Tables 4-14 and 4-15 present the capital and annual operating costs for the two systems evaluated (design evaluations are in Table 4-13). The evaluations represent the cost of equipment for the last quarter of 1977. They include only basic equipment (no spare equipment). The duct cost items in the three evaluations are based on a 24 m (80 ft) straight duct length from the existing ESP outlet to the inlet flange of the system, an appropriate length within the system, and a return duct of 34 m (110 ft) from the outlet to the existing stack. Capital charges in the annual operating costs were calculated by using 17.5 percent of the total turnkey costs. This rate is based on 10 percent interest rate, 15 years of equipment life, and a 4.35 percent rate for taxes and insurance.

The cost estimate data show that treating furnace gas in an add-on control system (Evaluation J) consisting of a fabric filter preceded by a water spray tower for cooling the gas to 120°C (250°F) costs about half of what it costs to treat the gas in a fabric filter preceded by air dilution for cooling the gas (Evaluation K). The turnkey capital cost of treating gas from the existing ESP outlet by the system in Evaluation J is \$380.11 per m^3/min (\$10.77 per acfm); by the method in Evaluation K this cost is \$751.58 per m^3/min (\$21.30 per acfm). The total cost of gas cleaning equipment (including auxiliaries) is about 37 percent of the total turnkey cost in Evaluation J and about 57 percent in Evaluation K. Annual operating cost for particulate removal is about \$0.14/kg (\$0.06/lb), or \$1607/day, for the

Table 4-14. CAPITAL COST DATA FOR ADD-ON CONTROL FABRIC FILTER SYSTEM FOR PHELPS DODGE CORPORATION SMELTER

Parameter	Evaluation J	Control system Evaluation K
System description	Spray water cooling of gas to 120°C (250°F), a fabric filter, followed by a fan	Dilution air cooling of gas to 120°C (250°F), a fabric filter, followed by a fan
Inlet gas flow:[a]		
Actual conditions	3700 m^3/min (130,690 acfm)	14,020 m^3/min (495,000 acfm)
Temperature	120°C (250°F)	120°C (250°F)
Standard conditions	2760 m^3/min (97,558 scfm)	10,460 m^3/min (369,500 scfm)
Moisture content	25.3%	3.0%
Contaminant loading:		
Inlet, concentration[b]	3.07 g/m^3 (1.34 gr/scf)	0.792 g/m^3 (0.346 gr/scf)
Inlet, weight rate[b]	508 kg/hr (1120 lb/hr)	497 kg/hr (1095 lb/hr)
Outlet, concentration	0.082 g/m^3 (0.036 gr/scf)	0.023 g/m^3 (0.01 gr/scf)
	13.6 kg/hr (30.0 lb/hr)	13.6 kg/hr (30.0 lb/hr)
Cleaning efficiency	97.3%	97.3%
Gas cleaning equipment cost	$498,000	$1,960,000
Cost of auxiliaries:		
Fan w/drive	47,800	310,000
Screw conveyor w/air lock	17,300	c
Cooling tower w/accessories	168,200	c
Total equipment cost	$731,300	$2,270,000

(continued)

Table 4-14 (continued).

Parameter	Evaluation J	Control system Evaluation K
Installation costs, direct:		
Foundation and supports	$ 45,000	
Duct work	188,300	$ 241,000
Stack	0	0
Piping	7,500	
Insulation	162,200	394,800
Painting	18,800	
Electrical	82,500	
Other	135,000	1,034,000
Total direct costs	$ 639,300	$1,669,800
Installation costs, indirect:		
Engineering	73,500	c
Constr. and field expenses	390,000	c
Construction fees	116,400	c
Start-up	12,700	11,000
Performance test	10,000	10,000
Contingencies	30,000	d
Total indirect costs	$ 632,600	$ 21,000
Turnkey cost	$ 2,003,200	$3,960,800

[a] To fabric filter from cooling system.

[b] Based on gas conditions at fabric filter inlet.

[c] Included in others.

[d] By others.

Table 4-15. ANNUAL OPERATING COST DATA FOR ADD-ON CONTROL FABRIC FILTER FOR PHELPS DODGE CORPORATION SMELTER

Parameter	Evaluation J	Control system Evaluation K
System description	Spray water cooling of gas to 120°C (250°F), a fabric filter, followed by a fan	Dilution air cooling of gas to 120°C (250°F), a fabric filter, followed by a fan
Inlet gas flow:[a]		
Actual conditions	3700 m^3/min (130,690 acfm)	14,020 m^3/min (495,000 acfm)
Temperature	120°C (250°F)	120°C (250°F)
Standard conditions	2760 m^3/min (97,558 scfm)	10,460 m^3/min (369,500 scfm)
Moisture content	25.3%	3.0%
Contaminant loading:[b]		
Inlet, concentration	3.07 g/m^3 (1.34 gr/scf)	0.792 g/m^3 (0.346 gr/scf)
Inlet, weight rate	508 kg/hr (1120 lb/hr)	497 kg/hr (1095 lb/hr)
Outlet, concentration	0.082 g/m^3 (0.036 gr/scf)	0.023 g/m^3 (0.024 gr/scf)
	13.6 kg/hr (30.0 lb/hr)	13.6 kg/hr (30.0 lb/hr)
Cleaning efficiency	97.3%	93.0%
Operating hours per year	8760	8760
DIRECT COSTS		
Operating labor:		
Operator, $10/man-hour	$29,200	$20,800
Supervisor, $12/man-hour	7,200	
Total	36,400	20,800

(continued)

Table 4-15 (continued).

Parameter	Evaluation J	Control system Evaluation K
Maintenance:		
Labor, $10/man-hour	30.200	4,200
Materials	700	84,600
Total	30,900	88,800
Replacement parts	17,500	
Utilities:		
Electricity, $0.03/kWh	140,400	260,000
Water, $0.025/1000 gal	10,800	0
Total	151,200	260,000
Total direct costs:	$ 236,000	$ 369,600
Capital charges	350,600	693,100
Total annual cost	$ 586,600	$1,062,700

[a] To fabric filter from cooling system.

[b] Based on gas conditions at fabric filter inlet.

system in Evaluation J and \$0.25/kg (\$0.11/lb), or \$2912/day, for the system in Evaluation K. Utilities costs represent about 25 percent of total annual operating costs for both systems.

Add-on Wet Scrubber Control System

Appendix C contains a specification for an add-on wet scrubber system at the Phelps Dodge smelter.

Three bidders used their best judgment to evaluate the scrubber system on the basis of this specification. Their evaluations are not comparable, however, because the individual systems are designed for different pressure drops (ΔP) across the system. System pressure drop, a principal design parameter, is usually determined by particulate size distributions and chemical analysis. Because of lack of sufficient data on these parameters, the bidders used their experience and judgment to determine pressure drop. Table 4-16 presents the design parameters of these evaluations (Evaluations L, M, and N).

In Evaluation L, ESP exhaust gas is treated at a rate of 5270 m^3/min (186,000 acfm) in a scrubber system consisting of an adjustable throat venturi, a flooded elbow, and an entrainment separator followed by a fan. Estimated pressure drop for this system is 17.43 kPa (70 in. W.C.). The venturi scrubber is made of 1/4-in. 316L SS. The flooded elbow, inlet and outlet transition pieces leading to and from the flooded elbow, the mist eliminator, and all connections are of 1/4-in. carbon steel with Ceilcote lining.

The scrubber system in Evaluation M consists of a fan and a quencher, followed by a venturi scrubber. This system operates at a pressure drop of 14.94 kPa (60 in. W.C.). The bidder believes this pressure drop and associated power requirements could be significantly lower, and

Table 4-16. DESIGN PARAMETERS OF ADD-ON SCRUBBER SYSTEM FOR PHELPS DODGE CORPORATION SMELTER

Parameter	Evaluation L	Control system Evaluation M	Evaluation N
System description	A venturi scrubber, flooded elbow, and mist eliminator, followed by a fan	A fan, separator quencher, and venturi scrubber	A prequencher, venturi scrubber, and separator, followed by a fan
Gas volume flow rate from the existing ESP to the system[a]			
Actual conditions	5270 m^3/min (186,000 acfm)	5270 m^3/min (186,000 acfm)	5270 m^3/min (186,000 acfm)
Actual temperature	314°C (598°F)	314°C (598°F)	314°C (598°F)
Standard conditions	2639 m^3/min (93,176 scfm)	2639 m^3/min (93,176 scfm)	2639 m^3/min (93,176 scfm)
Moisture content, percent	12.5	12.5	12.5
Particulate loading:			
Concentration	1.28 g/m^3 (0.56 gr/acf)	1.28 g/m^3 (0.56 gr/acf)	1.28 g/m^3 (0.56 gr/acf)
Weight rate	199.04 kg/hr (438.8 lb/hr)	199.04 kg/h (438.8 lb/hr)	199.04 kg/hr (447.2 lb/hr)
Quencher dimensions	2.44 m x 0.20 m x 5.56 m (8 ft x 0.67 ft x 18.25 ft)	4.57 m x 11.6 m (15 ft x 38 ft)	5.03 m x 12.2 m (16.5 ft x 40 ft)
Evaporative water addition to gas in the quencher	0.37 m^3/min (97.2 gpm)	0.36 m^3/min (94 gpm)	
Number of units	1	1	1
Gas volume flow rate at scrubber exit:			
Actual conditions	4431 m^3/min (156,455 acfm)	3643 m^3/min (128,661 acfm)	3462 m^3/min (122,250 acfm)
Temperature	66.1°C (151°F)	65.6°C (150°F)	66°F (150°F)
Standard conditions	3132 m^3/min (110,587 scfm)	3166 m^3/min 111,787 scfm)	2828 m^3/min (99,850 scfm)
Moisture content	21.0%	12.3%	12.0%
Pressure drop across scrubber	16.17 kPa (65 in W.C.)	+ 13.44 kPa (54 in W.C.)	- 5.23 kPa (21 in W.C.)
Particulate loading:			
Concentration	0.074 g/m^3 (0.32 gr/scf)	0.085 g/m^3 (0.037 gr/scf)	0.092 m^3/m (0.04 gr/scf)
Weight rate	13.93 kg/h (30.7 lb/hr)	15.65 kg/h (34.5 lb/hr	15.53 kg/h (34.23 lb/hr)
Scrubbing system cleaning efficiency	93% minimum	93% minimum	93% minimum
Scrubber water quantity (recycled)	13.14 m^3/min (3450 gpm)	2.3 m^3/min (607 gpm)	6.44 m^3/min (1700 gpm)
Venturi scrubber, water rate	17.55 m^3/min (4636 gpm)	2.44 m^3/min (643 gpm)	6.7 m^3/min 1771 gpm)
Makeup water addition rate	0.41 m^3/min (107 gpm)	0.49 m^3/min (130 gpm)	0.27 m^3/min (71 gpm)
Total scrubber pressure drop	17.43 kPa (70 in. W.C.)	12.45 kPa (50 in. W.C.)	5.23 kPa (21 in. W.C.)
Scrubber dimensions	0.28 m x 0.2 m x 5.56 m (8 ft x 0.67 ft x 18.25 ft)	2.2 m x 11.6 m (7.2 ft x 38 ft)	
Demister dimensions	0.24 m x 0.24 m x 0.6 m (8.5 ft x 8.5 ft x 2 ft)		
Fan location	Downstream of scrubber	Upstream of scrubber	Downstream of scrubber
Number of fans per unit	1		1
Total power required	1731 kW (2320 hp)	2080 kW (2788 hp)	714 kW (1038 hp)

that a pilot test should be made to determine actual pressure drop. The preconditioner is constructed of mild steel with a gunite or Savereisin acid-resistant cement lining. The scrubber would be 316L stainless steel to protect against scrubbing water, which is high in chlorides.

The scrubber system in Evaluation N consists of a prequencher, an adjustable-throat venturi scrubber, and a separator section, followed by a fan. The pressure drop of this system is 5.23 kPa (21 in. W.C.). The bidder indicated that some study has been made regarding scrubbing reverberatory furnace gases in copper smelters, and based on the limited scrubbing pilot plant data, he believes that a pressure drop of 5.23 kPa (21 in W.C.) is a reasonable selection for producing 96 to 98 percent efficiency by weight. The materials of construction are steel lined with acid brick, with FRP-lined steel in the hot gas zones and high velocity sections of the scrubber. All alloy parts are in Inconel 625 in the venturi. The fan wheel and shaft would be of Incoloy-825 or 904L material. The inlet ducting is of 1/4-in. and 3/8-in. carbon steel with exterior weatherproof insulation. The material of construction for the prequencher and venturi is 1/4-in. and 3/8-in. carbon steel with 60- to 80-mil flaked-glass lining plus 3-in. acid brick and foam glass interior lining. Alloy parts are of Inconel 625. The separator is 1/4-in. 3/8-in., and 1/2-in. carbon steel with 60- to 80-mil flaked-glass lining. The base, up to 2 ft above the gas inlet, is lined with 3-in. acid brick. The exit ducting to the fan and stack is of 5/8-in. thick FRP-Hetron 197 with flame retardant.

These evaluations point up the necessity of running pilot plant tests to evaluate a wet scrubber that will produce the desired efficiency.

Carbon steel is the material of construction for the water treatment systems in all three evaluations.

Add-on Wet Scrubber Control System Costs

Tables 4-17 and 4-18 present capital and annual operating costs of the three systems. The evaluations represent the cost of equipment for the last quarter of 1977. They include only basic equipment (no spare equipment). The following parameters were used in the duct cost estimate: a duct length of 24 m (80 ft) from the existing ESP exit to the add-on control system inlet, an appropriate duct length within the system, and a return duct of 34 m (110 ft) from the add-on system outlet to existing stack. Capital charges in the annual operating costs were calculated by using 20.5 percent of the total turnkey cost. This rate is based on an interest rate of 10 percent, an equipment life of 10 years, and a tax and insurance rate of 4.22 percent.

Data show that the turnkey capital cost estimates for an add-on scrubber system in the Evaluations L, M, and N are \$137, \$160, and \$390 per actual m^3/min (\$3.90, \$4.53 and \$11.05 per acfm), respectively, of gas entering the system. Gas flow rate to each system is 5270 m^3/min (186,000 acfm). Cost of gas cleaning equipment, including auxiliaries, varies from 40 to 60 percent of the total turnkey cost. The respective annual operating cost for the three systems are \$0.53, \$0.55 and \$0.45/kg (\$0.24, \$0.25 and \$0.20/lb) of particulate removed, or \$2407, \$2504, and \$2042 per day. Utilities and capital charges represent 54 percent and 17 percent of the total annual cost in Evaluation L, 67 percent and 19 percent in Evaluation M, and 30 percent and 57 percent in Evaluation N.

Table 4-17. CAPITAL COST DATA FOR AN ADD-ON SCRUBBER SYSTEM FOR PHELPS DODGE CORPORATION SMELTER

Parameter	Evaluation L	Evaluation M	Evaluation N
System description	A venturi scrubber, a flooded elbow and mist eliminator follow by a fan	A fan, a separator quencher and a venturi scrubber	A prequencher, a venturi scrubber, separator, followed by a fan
Gas flow at scrubber outlet:			
Actual conditions	4431 m^3/min (156,455 acfm)	3643 m^3/min (128,661 acfm)	3462 m^3/min (122,250 acfm)
Temperature	66.1°F (151°F)	65.6°C (150°F)	66°C (150°F)
Standard conditions	3132 m^3/min (110,587 acfm)	3166 m^3/min (111,787 acfm)	2828 m^3/min (99,850 acfm)
Moisture content	26.13%	Saturated	
Contaminant loading:[a]			
Inlet, concentration	1.28 g/m^3 (0.56 gr/scf)	1.28 g/m^3 (0.56 gr/scf)	1.28 g/m^3 (0.56 gr/scf)
Inlet, weight rate	240.8 kg/hr (530.8 lb/hr)	202.85 kg/hr (447.2 lb/hr)	202.85 kg/hr (447.2 lb/hr)
Outlet, concentration	0.087 g/m^3 (0.038 gr/scf)	0.087 g/m^3 (0.038 gr/scf)	0.087 g/m^3 (0.038 gr/scf)
Outlet, weight rate	13.6 kg/hr (30.0 lb/hr)	13.6 kg/hr (30.0 lb/hr)	13.6 kg/hr (30.0 lb/hr)
Cleaning efficiency	93.3%	93.3%	93.3%
Gas Cleaning equipment cost	$102,500	$120,100	$535,000
Cost of auxiliaries:			
Fan w/drive	92,000	90,000	140,000
Pumps	11,500	20,000	33,000
Tanks		60,000	12,000
Wastewater treatment[b]	116,800	118,500	105,000
Others	16,500	87,100	
Total equipment cost	$339,300	$495,700	$ 825,000
Installation cost, direct:			
Foundation and supports	$ 26,000	$ 59,400	
Duct work	146,000	127,000	$ 123,500
Stack	0	0	0
Piping	12,500	42,900	
Insulation	18,700	18,500	
Painting	5,000	4,000	
Electrical	3,000	27,200	
Other	50,000		
Total direct costs	$261,200	$279,000	$1,108,300[c]
Installation costs, indirect:			
Engineering	$ 8,700	$ 16,000	
Construction & field expenses	92,000	18,000	
Construction fees	1,300	5,000	
Start-up	2,000	7,000	
Performance test	4,800	12,000	
Contingencies	15,000	10,000	
Total indirect costs	$123,800	$ 68,000	
Turnkey cost	$724,300	$842,700	$2,056,800

[a] Based on system inlet, (i.e. particulate content in the gas flow rate) of 2639 m^3/min (93,176 acfm) to the system.

[b] Materials and labor.

[c] Total of direct and indirect costs, excluding duct cost.

Table 4-18. ANNUAL OPERATING COST DATA FOR ADD-ON SCRUBBER FOR PHELPS DODGE CORPORATION SMELTER

Parameter	Evaluation L	Evaluation M	Evaluation N
System description	A venturi scrubber, a flooded elbow, and a mist eliminator, followed by a fan	A fan, a separator quencher, and a venturi scrubber	A prequencher, a venturi scrubber, and a separator, followed by a fan
Gas flow at scrubber outlet:			
Actual conditions	4431 m^3/min (156,455 acfm)	3643 m^3/min (128,661 acfm)	3462 m^3/min (122,250 acfm)
Temperature	66.1°C (151°F)	65°C (150°F)	66°C (150°F)
Standard conditions	3132 m^3/min (110,587 scfm)	3166 m^3/min (111,787 scfm)	2828 m^3/min (99,850 scfm)
Moisture	26.13%	Saturated	
Contaminant loading:[a]			
Inlet, concentration	1.28 g/m^3 (0.56 gr/scf)	1.28 g/m^3 (0.56 gr/scf)	1.28 g/m^3 (0.56 gr/scf)
Inlet, weight rate	202.85 kg/hr (447.2 lb/hr)	202.85 kg/hr (447.2 lb/hr)	202.85 kg/hr (447.2 lb/hr)
Outlet, concentration	0.087 g/m^3 (0.038 gr/scf)	0.087 g/m^3 (0.038 gr/scf)	0.087 g/m^3 (0.038 gr/scf)
Outlet, weight rate	13.6 kg/h (30.0 lb/hr)	13.6 kg/hr (30.0 lb/hr)	13.6 kg/hr (30.0 lb/hr)
Cleaning efficiency	93.3%	93.3% (minimum)	93.3%
Operating hours per year	8760	8760	8760
DIRECT COSTS			
Operating labor:			
Operator, $10/man-hour	$122,200	$ 87,600	$27,100
Supervisor, $12/man-hour	37,000	24,000	9,700
Total	159,200	111,600	36,800
Maintenance			
Labor, $10/man-hour	59,200	3,600	27,100
Materials	25,600	3,000	18,500
Total	84,800	6,600	45,600
Replacement parts	16,200	10,000	18,500
Utilities			
Electricity, $0.03/kWh	450,700	576,800	196,000
Water, $0.25/1000 gallons	14,100	12,400	7,500
Chemicals	5100	23,800	19,400
Total	469,900	613,000	222,900
Total direct costs	$730,100	$741,200	$323,800
Capital charges	148,500	172,800	421,600
Total annual cost	$878,600	$914,000	$745,400

[a] Based on system inlet (i.e. particulate content in the gas flow rate) of 2639 m^3/min (93,176 scfm) to the system.

Add-on Dry Electrostatic Precipitator (ESP) System

Appendix C presents the specification for an add-on dry ESP for the Phelps Dodge smelter in Ajo. Three IGCI members used their best judgment to evaluate a dry ESP system based on this specification. Table 4-19 presents design parameters of the systems evaluated.

The system in Evaluation P consists of an evaporative cooling tower to cool gases from the existing hot ESP to 120°C (250°F), followed by a dry ESP for particulate control. The fan, necessary to overcome 0.96 kPa (4 in. W.C.), is located on the hot side of the evaporative cooling tower to avoid possible corrosion and imbalance problems. Design and instrumentation of the cooling tower spray chambers must be precise to keep the exit gas dry because wet gas in the ESP can cause a corrosion problem and lead to premature system failure. An ESP pilot study would be required to assess the corrosive and "sticky" nature of the flue gas and particulate load.

The particulate control add-on system in Evaluation Q consists of a combination heat exchanger and dilution air to cool the gas to 120°C (250°F) and two dry ESP's in parallel. The fan is located upstream of the cooling system to take advantage of the smaller gas stream which requires less power, and to prevent corrosion and imbalance problems. The combination heat exchanger and dilution air cooling is believed to be the most economic from the viewpoint of cost per Btu transferred and prevention of an increase in the sticky and corrosive nature of the gas stream that is caused by water spray cooling.

The add-on system in Evaluation R consists of a water-spray cooling tower, which cools the gas to 120°C (250°F), and a dry ESP for particulate control. The fan is located

Table 4-19. DESIGN PARAMETERS FOR ADD-ON DRY ELECTROSTATIC PRECIPITATOR FOR PHELPS DODGE CORPORATION SMELTER

Parameter	Evaluation P	Evaluation Q	Evaluation R
System description	A fan and an evaporative cooling tower to cool gas to 120°C (250°F), followed by a dry electrostatic precipitator	A fan, two heat exchangers, and a dilution air fan to cool gas to 120°C (250°F), followed by a dry electrostatic precipitator	A fan and water spray cooling to 120°C (250°F), followed by electrostatic precipitator
Gas volume flow rate from the existing electrostatic precipitator to cooling system:			
Actual conditions	5267 m^3/min (186,000 acfm)	5267 m^3/min (186,000 acfm)	5267 m^3/min (186,000 acfm)
Standard conditions	2633 m^3/min (93,000 scfm)	2633 m^3/min (93,000 scfm)	2633 m^3/min (93,000 scfm)
Temperature	314°C (598°F)	314°C (598°F)	314°C (598°F)
Moisture content	12.25%	12.25%	12.25%
Type of cooling	Evaporative cooling tower	Heat exchanger and dilution air[a]	Water spray cooling
Number of units	1	2[b]	1
Dimensions of each unit		5.2 m x 5.2 m x 3.7 m (17 ft x 17 ft x 12 ft)[b]	
Water consumption	1.02 m^3/h (270 gpm)		
Dilution air		629 m^3/min 22,192 acfm)	
Total volume flow rate to add-on precipitator system inlet or cooling system outlet:			
Actual conditions	4078 m^3/min (144,000 acfm)	4371 m^3/min (154,375 acfm)	3535 m^3/min (124,820 acfm)
Standard conditions	3046 m^3/min (107,650 scfm)	3262 m^3/min (155,192 acfm)	2149 m^3/min (75,900 scfm)
Temperature	120°C (250°F)	120°C (250°F)	120°C (250°F)
Number of ESP's	1	1	2
Dimension of each	14.3 m x 12.8 m x 14.3 m (47 ft x 42 ft x 47 ft)	1.95 m [illegible] x 9.34 m (64 ft L x 30.67 [illegible] W)	14.9 m x 12.9 m x 18.0 m (49 ft x 42.5 ft x 59.1 ft)
Number of chambers per ESP	2	1	1
Number of fields	4	4[c]	3
Number of passages per chamber	21	30	20
Length of each field	2.7 m (9.0 ft)	1.33 m (10.94 ft)	2.78 m (9.125 ft)
Field height	7.3 m (24 ft)	9.40 m (30.83 ft)	5.18 m (17 ft)
Number of energizing means	8	4	3
Current	1000 mA	1250 mA	1300 mA
Voltage	70 kV	55 kV	45 kV
Wave form	Full	Full	Full
Migration velocity	0.04 m/s (0.13 ft/s)	0.41 m/s (0.133 ft/s)	0.0322 m/s (0.0098 ft/s)
Specific collecting area	74.4 m^2 per m^3/s (378 ft^2/1000 acfm)[d]	77.4 m^2 per m^3/s (393 ft^2/1000 acfm)[e]	58.7 m^2 per m^3/s (298 ft^2/1000 acfm)
Total power consumption	945 kW	680 kW	233 kW
Fan:			
Number	1	1	1
Location	Hot side of cooling tower	Hot side of cooling system	Hot side of cooling tower
Pressure drop	0.996 kPa (4 in. W.C.)	1.992 kPa (8 in. W.C.)	1.793 kPa (-7.2 in. W.C.)
Power required	280 kW (375 hp)	294 kW (335 hp)	297 kW (400 hp)

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[a] Heat exchanger cools gas to 177°C (350°F) and dilution air further cools gas to 120°C (250°F).

[b] Pertains only to heat exchanger.

[c] One field is redundant.

[d] Net gross 99.2 m^3 per m^3/s (504 ft^2/1000 acfm).

[e] Net gross 103 m^2 per m^3/s (524 ft^2/1000 acfm).

on the hot side of the cooling tower to prevent corrosion and imbalance problems that can occur with this type of gas.

Costs of an Add-on Dry Electrostatic Precipitator

Tables 4-20 presents the capital cost breakdown for the evaluations P, Q, and R. Table 4-21 presents the annual operating cost breakdown for Evaluations P, Q and R. The evaluations represent the cost of equipment during the quarter of 1977. They include only basic equipment (no spare equipment). Duct cost estimates in the three evaluations are based on 24 m (80 ft) of duct from the existing ESP outlet to the inlet of the system, an appropriate length within the system, and a return duct of 34 m (110 ft) from the system flange to the existing stack. Capital charges in the annual operating costs were calculated by using 17.5 percent of the total turnkey costs. This rate is based on an interest rate of 10 percent, an equipment life of 15 years, and tax and insurance rate of 4.35 percent.

The data show that the use of an add-on dry ESP system to enable Phelps Dodge Corporation to comply with the applicable emission regulation will entail capital costs of \$329 to \$466 per m^3/min (\$9 to \$13 per acfm) of ESP exhaust gas, depending on the type of cooling system involved. A gas flow rate of 5267 m^3/min (186,000 acfm) is used as the basis for all three evaluations. System P, which uses an evaporative cooling tower for gas cooling and a dry ESP for particulate control, costs \$367.12 per m^3/min (\$10.40 per acfm) of gas introduced into the system. System Q, which uses a heat exchanger and dilution air cooling system and two dry ESP's in parallel for particulate control, costs \$465.62 per m^3/min (\$13.19 per acfm). System R which uses a water spray cooling tower for gas cooling followed by a dry ESP for particulate control, costs \$329.35 per m^3/min

Table 4-20. CAPITAL COST DATA FOR ADD-ON DRY ELECTROSTATIC PRECIPITATOR SYSTEM

FOR PHELPS DODGE CORPORATION SMELTER

Parameter	Evaluation P	Evaluation Q	Evaluation R
System description	A fan and an evaporative cooling tower that cools gas to 120°C (250°F), followed by a dry ESP	A fan, two heat exchangers, and a dilution air fan to cool gas to 120°C (250°F) followed by a dry ESP	A fan and water spray cooling to 120°C (250°F), followed by a dry ESP
Inlet gas flow:			
Actual conditions	4078 m^3/min (144,000 acfm)	4371 m^3/min (154,375 acfm)	3535 m^3/min (124,820 acfm)
Standard conditions	3044 m^3/min (107,490 acfm)	2362 m^3/min (115,192 acfm)	2149 m^3/min (75,900 acfm)
Temperature	120°C (250°F)	120°C (250°F)	120°C (250°F)
Contaminant loading[a]			
Inlet, concentration	1.28 g/m^3 (0.56 gr/acf)	1.28 g/m^3 (0.56 gr/acf)	1.28 g/nm^3 (0.56 gr/acf)
Inlet, wt. rate	199.04 kg/hr (438.8 lb/hr)	199.04 kg/hr (438.8 lb/hr)	199.04 (kg/hr (438.8 lb/hr)
Outlet, concentration	0.087 g/m^3 (0.038 gr/acf)	0.087 g/m^3 (0.038 gr/acf)	0.087 g/nm^3 (0.038 gr/acf)
Outlet, wt. rate	13.6 kg/hr (30.0 lb/hr)	13.6 kg/hr (30.0 lb/hr)	13.6 kg/hr (30.0 lb/hr)
Cleaning efficiency	93.2%	93.2%	93.2%
Gas cleaning equipment cost	$ 645,000	$470,000	$555,900
Cost of auxiliaries:			
Fan w/drive	87,000	87,500	65,000
Dry cooling chamber	168,000	277,000	168,000
Other	123,600[b]	78,000[c]	97,800[d]
Total equipment cost	1,023,600	912,500	886,700
Installation costs, direct:			
Foundation and supports[e] (material & labor)	112,000	58,000	7,500
Duct work[f]	175,100	154,000	168,100
Stack	0	0	
Piping	Not quoted	Not quoted	Not quoted
Insulation (material & labor)	0	0	0
Painting	Not quoted	Not quoted	93,000
Electrical (material & labor)		75,000	55,000
Other	505,600[g]	729,400[h]	368,600[i]
Total direct costs	$ 792,700	$1,008,400	$ 692,200
Installation costs, indirect:			
Complete erection	[j]		
Engineering	[j]	281,000	[k]
Construction & field expenses	[j]	63,000	49,800
Construction fees	[j]	36,000	
Start-up	12,500	12,000	5,900
Performance test	[k]	7,500	25,700
Model study	9,000	31,000	
Contingencies	96,000	101,000	74,400
Total indirect costs	117,500	531,500	155,800
Turnkey cost	$1,933,800	$2,452,400	$1,734,700

[a] Particulate content of the gas at the inlet and outlet is based on the gas flow rate of 2639 m^3/min (93,176 acfm) to the system.

[b] Includes screw conveyors, slide gates and lower dampers.

[c] Access and dust disposal.

[d] Slide-gate conveyors, dampers.

[e] Includes only material and labor for precipitator supports.

[f] Includes duct, insulation, lining, materials and labor.

[g] Includes cost of erection labor for total gas cleaning equipment, direct costs of electrical arrangements, and indirect costs connected with engineering and construction.

[h] Installation costs for the gas cleaning equipment and auxiliaries.

[i] About 92.5 percent for installation of total gas cleaning equipment and remaining for freight on equipment.

[j] Included in "other".

[k] Included in cost of start-up.

Table 4-21. ANNUAL OPERATING COST DATA FOR ADD-ON CONTROL DRY ELECTROSTATIC PRECIPITATOR FOR PHELPS DODGE CORPORATION SMELTER

Parameter	Evaluation P	Control system Evaluation Q	Evaluation R
System description	A fan, an evaporative cooling tower cooling gas to 120°C (250°F), followed by a dry electrostatic precipitator	A fan, two heat exchangers, a dilution air fan, to cool gas to 120°C (250°F), followed by a dry electrostatic precipitator	A fan, water spray cooling to 120°C (250°F), followed by a dry electrostatic precipitator
Inlet gas flow:			
Actual conditions	4078 m³/min (149,000 acfm)	4371 m³/min (154,374 acfm)	3535 m³/min (124,820 acfm)
Standard conditions	3044 m³/min (107,490 scfm)	3262 m³/min (115,192 scfm)	2149 m³/min (75,900 scfm)
Temperature	120°C (250°F)	120°C (250°F)	120°C (250°F)
Contaminant loading:[a]			
Inlet, concentration	1.28 g/m³ (0.56 gr/scf)	1.28 g/m³ (0.56 gr/scf)	1.04 gr/m³ (0.456 gr/scf)
Inlet, wt. rate	199.04 kg/hr (438.8 lb/hr)	199.04 kg/hr (438.8 lb/hr)	199.04 kg/hr (438.8 lb/hr)
Outlet, concentration	0.087 g/m³ (0.038 gr/scf)	0.087 g/m³ (0.038 gr/scf)	0.087 g/m³ (0.038 gr/scf)
Outlet, wt. rate	13.6 kg/hr (30.0 lb/hr	13.6 kg/hr (30.0 lb/hr)	13.6 kg/hr (30.0 lb/hr)
Cleaning efficiency	93.2%	93.2%	93.2%
Operating hours per year	8760	8760	8760
DIRECT COSTS			
Operating labor:			
Operator, $10/man-hour	$ 8,100	$ 10,700	$ 5,500
Supervisor, $12/man-hour	1,900	1,500	2,300
Total	10,000	12,200	7,800
Maintenance			
Labor, $10/man-hour	4,200	4,200	4,000
Materials	2,200	2,600	2,200
Total	6,400	6,800	6,200
Replacement parts	1,800	b	1,400
Utilities			
Electricity, $0.03 kWh	248,000	178,700	99,600
Water, $0.25/1000 gal	10,800	0	10,800
Total	258,800	178,700	110,400
Total direct costs	$277,000	$197,700	$125,800
Capital charges	344,000	429,200	303,600
Total annual cost	$621,000	$626,900	$429,400

[a] Particulate content of the gas at the inlet and outlet is based on a gas flow rate of 2639 m³/min (93,176 scfm) to the system.

[b] Included in maintenance.

($9.33 per acfm). Cost of gas cleaning equipment including auxiliaries for the Evaluations P, Q, and R, respectively, is 53 percent, 37 percent, and 51 percent of the total turnkey capital charges. Annual operating costs are $0.38/kg ($0.17/lb) or $1701/day, of particulate removed for Evaluation P; $0.39/kg ($.18/lb), or $1718/day, for Evaluation Q; and $0.26/kg ($0.12/lb), or $1176/day, for Evaluation R. Utility costs and capital charges represent about 97 percent of the total annual operating costs for all three evaluations.

Add-on Wet Electrostatic Precipitator (WEP) Control System

Appendix C contains the specification for an add-on wet ESP at the Phelps Dodge smelter. Based on the specification, one IGCI member used his best judgment to evaluate a system. Table 4-22 presents the design parameters of that system (Evaluation S).

The system involves a WEP designed to receive gases from an evaporative cooling tower at 120°C (250°F). The system consisting of a fan, an evaporative cooling tower, and a WEP. The fan is located upstream of the cooling system to prevent a potential corrosion problem. The WEP is generally chosen when the particulate tends to be sticky and does not drop when the plates of a dry ESP are rapped. The WEP is a continuously sprayed, horizontal flow, parallel plate, and rigid frame discharge electrode type. Water from a precisely designed water nozzle arrangement is sprayed at the WEP entrance to maintain a low resistivity of the particles entering into the system. Water sprays located above the electrostatic field sections introduce evenly distributed water droplets to the gas stream for washing all internal surfaces. The particulates and water droplets in the electrostatic field pick up charges and migrate to the collecting plates. The plates are continuously flushed to

Table 4-22. DESIGN PARAMETERS OF AN ADD-ON CONTROL WET ELECTROSTATIC PRECIPITATOR SYSTEM FOR THE PHELPS DODGE CORPORATION SMELTER

Parameter	Evaluation S
System description	One evaporative cooling tower to cool gas to 120°C (250°F), one fan, and one wet ESP
Gas volume flow rate from the existing ESP to the cooling system:	
Actual conditions	5267 m^3/min (186,000 acfm)
Standard conditions	2633 m^3/min (93,000 scfm)
Temperature	314°C (598°F)
Moisture content	12.25%
Type of cooling system	Evaporative cooling tower
Number of units	1
Dimensions of each unit	7.99 m x 18.8 m (26.24 ft x 61.7 ft)
Liquid-to-gas ratio, L/G	0.097 m^3 per m^3/min (355 gal/1000 acfm)
Electrostatic Precipitator System	
Total volume flow rate to add-on precipitator system inlet or cooling system outlet:	
Actual conditions	4046 m^3/min (142,892 acfm)
Standard conditions	3021 m^3/min (106,673 scfm)
Temperature	120°C (250°F)
Number of ESP's	1
Dimension of each	

(continued)

Table 4-22 (continued).

Parameter	Evaluation S
Number of chambers per ESP	1
Number of fields	3[a]
Number of passages per chamber	22
Length of each field	3.33 m (10.92 ft)
Field height	7.87 m (25.83 ft)
Number of energizing means	3
Current	1250 mA
Voltage	55 kV
Wave form	Full
Migration velocity	0.0774 m/s (0.254 ft/s)
Specific collecting area	34.3 m^2 per m^3/s (128 ft^2/1000 acfm)[b]
Spray water	3.051 m^3/min (806 gpm)
Flushing water for inlet transition	9.08 m^3/min (240 gpm)
Flushing water for ESP plates	8.244 m^3/min (2178 gpm)
Fan:	
Location	Hot side of cooling system
Number	1
Pressure drop	1.992 kPa (8 in. W.C.)
Power required	261 kW (250 hp)

[a] One field is redundant.

[b] Net, 51.3 $m^2/m^3/s$, (193 ft^2/1000 acfm) gross.

remove the collected material into the troughs below which are sloped to a drain. The WEP parts not sprayed or flushed with water are constructed of corrosion-resistant materials. (The portion close to outlet of WEP is not sprayed or flushed with water in order to remove the carry over liquid drops and mists before the outlet of the equipment). The condensible material collected in the drain liquor can be separated by means of any sludge removal methods.

Costs of Add-on WEP System

Tables 4-23 and 4-24 present capital and annual operating cost breakdowns for Evaluation S. The evaluation represents the cost of equipment during the last quarter of 1977. It includes only basic equipment (no spares). Duct cost estimates in the evaluation are based on 24 m (80 ft) of duct from the existing ESP outlet to the inlet of the system, an appropriate length within the system, and a return duct of 34 m (110 ft) from the system to existing stack. Capital charges in the annual operating costs were calculated by using 17.5 percent of the total turnkey costs. This rate is based on an interest rate of 10 percent, an equipment life of 15 years, and a tax and insurance rate of 4.35 percent.

The data show that the capital cost of an add-on wet ESP system to enable Phelps Dodge Corporation to comply with the applicable emission regulation is \$384.17 per m^3/min (\$10.88 per acfm) of ESP exhaust gas [based on a flow rate of 5,267 m^3/min (186,000 acfm)]. The evaluated system uses an evaporative cooling system to cool the gas to 120°C (250°F) before it enters the WEP. Cost of gas cleaning equipment including auxiliaries is 43 percent of the total turnkey capital charges. Annual operating costs for particulate removal are \$0.35/kg (\$0.16/lb), or \$1547 per day. Utility costs and capital charges represent about 98 percent of the total annual operating costs.

Table 4-23. CAPITAL COST DATA FOR AN ADD-ON WET ELECTROSTATIC PRECIPITATOR SYSTEM FOR PHELPS DODGE CORPORATION SMELTER

Parameter	Evaluation S
System description	One evaporative cooling tower to cool the gas to 120°C (250°F), one fan, and one wet ESP
Inlet gas flow:	
Actual conditions	4046 m^3/min (142,898 acfm)
Standard conditions	3021 m^3/min (106,673 scfm)
Temperature	120°C (250°F)
Contaminant loading:[a]	
Inlet, concentration	1.28 g/m^3 (0.56 gr/scf)
Inlet, wt. rate	199.04 kg/hr (438.8 lb/hr)
Outlet, concentration	0.087 g/m^3 (0.038 gr/scf)
Outlet, wt. rate	13.6 kg/hr (30.0 lb/hr)
Cleaning efficiency	93.2%
Gas cleaning equipment cost	$ 435,100
Cost of auxiliaries:	$ 28,000
Fan with drive	87,500
Evaporative cooling tower	314,000
Total equipment cost	$ 864,600
Installation costs, direct	
Recipitator supports (M&L)	$ 23,500
Duct work	154,400[b]

(continued)

Table 4-23 (continued).

Parameter	Evaluation S
Stack	0
Piping	
Insulation (material & labor)	
Painting	
Electrical (material & labor)	87,500
Other	340,900[c]
Total direct costs	$ 606,300
Installation costs, indirect	
Engineering	$ 350,000[d]
Construction and field expenses	52,000
Construction fees	36,000
Start-up	12,000
Performance test	7,500
Contingencies	95,000
Total indirect costs	$ 552,500
Turnkey cost	$2,023,400

[a] Particulate content of the gas at the inlet and outlet based on a gas flow rate of 2639 m^3/min (93,176 scfm) to the system.

[b] Includes duct, insulation lining, materials and labor.

[c] Installation cost of ESP, auxiliaries, and fan.

[d] Includes $31,000 model study.

Table 4-24. ANNUAL OPERATING COST DATA FOR ADD-ON CONTROL WET ELECTROSTATIC PRECIPITATOR FOR PHELPS DODGE CORPORATION SMELTER

Parameter	Evaluation S
System description	One evaporative cooling tower to cool gas to 120°C (250°F) and one fan, followed by one ESP
Inlet gas flow:	
Actual conditions	4046 m^3/min (142,898 acfm)
Standard conditions	3021 m^3/min (106,673 scfm)
Temperature	120°C (250°F)
Contaminant loading:	
Inlet, concentration	1.28 g/m^3 (0.56 gr/scf)
Inlet, wt. rate	199.04 kg/hr (438.8 lb/hr)
Outlet, concentration	0.087 g/m^3 (0.038 gr/scf)
Outlet, wt. rate	13.6 kg/hr (30.0 lb/hr)
Cleaning efficiency	93.2%
Operating hours per year	8760
Direct costs	
Operating labor	
Operator, $10/man-hour	$ 7100
Supervisor, $12/man-hour	1500
Total	8600
Maintenance	
Labor, $10/man-hour	3500
Materials	2300
Total	5800

(continued)

Table 4-24 (continued).

Parameter	Evaluation S
Replacement parts	a
Utilities	
Electricity, $0.03/kWh	76,900
Water, $0.25/1000 gal	119,200
Chemicals	b
Total	196,100
Total direct costs	$ 210,500
Capital charges	354,000
Total annual cost	$ 564,500

[a] Included in maintenance cost.

[b] Included in electricity cost.

APPENDIX A

CONVERSION FACTORS

To convert English units	Multiply by	To obtain SI units
British thermal unit (Btu)	1056	Joule (j)
Cubic foot (ft^3)	0.0283	Cubic meter (m^3)
Degrees fahrenheit	5/9 (°F-32)	Degrees Celsius (C)
Foot	0.3048	Meter (m)
Gallon (U.S. liquid)	0.0038	Cubic meter (m^3)
Gallon (U.S. liquid)	3.7854	Liter (l)
Horsepower (hp)	746.0	Watt (w)
Inch	0.0254	Meter (m)
Inches of water	248.8	Pascal (pa)
Pound	0.4536	Kilogram (kg)

APPENDIX B

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TECHNICAL SPECIFICATIONS FOR ADD-ON CONTROL SYSTEMS FOR REVERBERATORY FURNACE AT MAGMA COPPER COMPANY, SAN MANUEL, ARIZONA

Prepared by

PEDCo Environmental, Inc.
11499 Chester Road
Cincinnati, Ohio 45246

PEDCo Project Number: 3287-B

June 28, 1977

CHESTER TOWERS

BRANCH OFFICES

Crown Center
Kansas City, Mo

Professional Village
Chapel Hill, N.C.

B-1-a

TABLE OF CONTENTS

	Page
SCOPE OF WORK	1
GENERAL INFORMATION	3
DESIGN CRITERIA AND GUARANTEE	3
SPECIFIC OPERATING CONDITIONS FOR ADD-ON EQUIPMENT	5
DESIGN LOADS	6
CONTROL SYSTEM SUPPORT STRUCTURE	12
ADD-ON CONTROL EQUIPMENT: ELECTROSTATIC PRECIPITATOR, DRY TYPE	12
ADD-ON CONTROL EQUIPMENT: ELECTROSTATIC PRECIPITATOR, WET TYPE	18
ADD-ON CONTROL EQUIPMENT: COOLING CHAMBERS	19
ADD-ON CONTROL EQUIPMENT: VENTURI SCRUBBER	20
ADD-ON CONTROL EQUIPMENT: FABRIC FILTER BAGHOUSE	21
SKETCHES	A-1

LIST OF TABLES

No.		Page
1	Summary of Particulate Emission Data for Electrostatic Precipitator on Reverberatory Furnace - Magma Copper Company, San Manuel, Arizona	7

LIST OF SKETCHES

No.		Page
A-1	Dry Electrostatic Precipitator with a Cooling Chamber	A-1
A-2	Wet Electrostatic Precipitator with a Cooling Chamber	A-2
A-3	Wet Electrostatic Precipitator	A-3
A-4	Cooling Chamber	A-4
A-5	Venturi Scrubber	A-5
A-6	Fabric Filter Baghouse	A-6

TECHNICAL SPECIFICATIONS (COPPER SMELTER)

It is the intent of these specifications to provide the contractor with sufficient information to furnish and install a gas-cleaning system, including the control equipment to treat exhaust gases from an already-installed electrostatic precipitator on a copper concentrate smelting reverberatory furnace at the Magma plant at San Manuel, Arizona.

SCOPE OF WORK

Major items of work to be accomplished by contractor consist of the following:

1. Engineer, design, procure materials and equipment, fabricate, and erect from ground level from the discharge of the existing hot electrostatic precipitator flue to the inlet nozzles of the required add-on control equipment. The contractor shall provide heat insulation on flues.
2. Engineer, design, procure materials and equipment, fabricate, and erect from ground level up the required support structure for the add-on control equipment, including all required walkways, stairways, and handrails. The supporting structure

system will exclude foundations, which will be supplied and furnished by others.

3. Engineer, design, procure materials and equipment, fabricate and deliver add-on control equipment, complete with all electrical equipment required to place the unit into operation.

4. Erect the add-on control equipment, including furnishing and installing heat insulation on the add-on control equipment where required. The erection portion excludes furnishing wire and conduit or a control room for electrical equipment.

5. Engineer, design, procure materials and equipment, fabricate, and erect from ground level up the discharge flues starting at the outlet nozzle flange of the add-on control equipment and terminating at the new inlet to the present stack.

6. Provide qualified personnel for the initial start-up of the complete system. Start-up is to include all testing, adjustments, and modifications necessary to ensure proper operation of the units at or above the collection efficiency levels specified herein. Start-up is also to include the training of owner's operating and maintenance personnel to operate and maintain the equipment.

7. The contractor shall provide the services of a qualified Field Erection Engineer who shall give supervision and technical assistance as required during assembly, field erection, and start-up of the equipment.
8. The contractor will furnish a test model of the add-on control equipment and the flue systems for gas-flow study.

GENERAL INFORMATION

An additional fan to handle the pressure drop shall be included with any add-on control equipment.

All electrical, water, and other services will be within 100 feet of the new facilities.

Site leveling and preparation by others.

The units are to operate 24 hours per day, 365 days per year.

The layouts for particulate removal control systems are shown on attached Sketches A-1 through A-6. The length of duct runs are shown on the sketches.

DESIGN CRITERIA AND GUARANTEE

1. Collection Efficiency

   The add-on control equipment will have a minimum guaranteed collection efficiency of 98.2 percent by weight of the entering particulate matter as determined by EPA Test Method 5, with a filter temperature of 250°F.

2. Efficiency Tests

The owner shall make regular tests to check the collecting efficiency. The contractor and owner shall jointly test the add-on control equipment for collection efficiency immediately after completion of all construction, at 6 months and at 11 months after completion. The test at 11 months will determine the guarantee performance.

3. Efficiency Curves

The contractor shall furnish with its proposal expected efficiency curves, showing the guarantee point. Curves will show expected efficiency versus volume, grain loading, percent moisture, gas temperature, percent SO_3 in gas, percent lead, and any other significant parameters affecting efficiency of the add-on control equipment.

4. Draft Loss

The draft loss between inlet and outlet flanges of the nozzles will be held to a minimum to attain the removal efficiency required.

5. Gas Velocity

The gas velocity through the precipitator proper will not exceed 3 feet per second; and the velocity through a venturi scrubber or baghouse shall be recommended by the vendor.

6. Gas Flow Study

The contractor shall construct a test model of the system from and including the outlets of the waste heat boilers to the stack.

7. Redundancy

The control equipment shall be sized with a confidence level of at least 90 percent when the system is operating at a full mode.

SPECIFIC OPERATING CONDITIONS FOR ADD-ON CONTROL EQUIPMENT

The add-on control equipment will be capable of handling copper smelting reverberatory furnace exhaust gases described as follows:

1. Amount of gases per precipitator: 329,000 scfm. (641,000 acfm)
2. Operating temperature of gases: 573°F.
3. Short-term temperature surges to 650°F during furnace charging periods.
4. Nominal dust particle inlet loading is 0.77 grain per SCF. Estimated dust particulate inlet loading is 1.25 grains per SCF during furnace charging periods.

5. Particle size analysis - flue gas at 573°F contained about 77 cummulative percent particulate present in a size less than 7 micrometers and about 26 cummulative percent particulate present in a size less than 0.26 micrometers.

6. Expected volumetric analysis of gas component and percent: See attached Table 1.

7. Estimated bulk density of collected dust, dry pounds per cubic foot: Not available.

8. Acid dew point of gas: Not available.

9. Expected composition of dust: See attached Table 1 and use outlet composition.

DESIGN LOADS

This should include vertical live loads, lateral loads, and earthquake considerations.

FLUE SYSTEM:

1. The flue system shall begin at the outlet flange of the existing hot electrostatic precipitator and proceed to the inlet flanges of the add-on control equipment.

2. The ductwork from the outlet flange of the existing hot electrostatic precipitator to the add-on control equipment shall be sized for minimum gas velocity of 3500 feet per minute under maximum

Table 1. SUMMARY OF PARTICULATE EMISSION DATA FOR EXISTING ELECTROSTATIC PRECIPITATOR ON REVERBERATORY FURNACE - MAGMA COPPER COMPANY, SAN MANUEL, ARIZONA

Item	Design (1)[a]	Actual (1)	Compliance tests conducted by company October 30 and 31, 1975 (2)	EPA compliance tests by NEIC May 14 to 18, 1976 (3)
ESP manufacturer	Research Cottrell			
ESP Inlet Conditions				
Volume flow at continuous rating, acfm	560,000 (Calc.)	560,000 (calc.)		
scfm	284,000	284,000		
Temperature, °F	500-670	500-670		
Gas dust loadings:				
by instack filter, gr/scf	0.836	0.836		
lb/hr	2035 (calc.)	2035 (calc.)		
by instack/outstack filter, gr/scf				
lb/hr				
by EPA Test Method 5, gr/scf				
lb/hr				
ESP Outlet Conditions				
Volume flow at continuous rating acfm			331,200[b]	329,000[c]
scfm			170,000	169,000

Table 1 (Cont'd). SUMMARY OF PARTICULATE EMISSION DATA FOR EXISTING ELECTROSTATIC PRECIPITATOR ON REVERBERATORY FURNACE - MAGMA COPPER COMPANY, SAN MANUEL, ARIZONA

Item	Design (1)[a]	Actual (1)	Compliance tests conducted by company (2) October 30 and 31, 1975	EPA compliance tests by NEIC May 14 to 18, 1976 (3)
ESP Outlet Conditions (continued)				
Temperature, °F			573	573
Gas dust loadings:				
by instack filter				
gr/scf	0.01254			
lb/hr	30.53 (calc.)			
by instack/outstack filter,				
gr/scf				
lb/hr				
by EPA Test Method 5,				
gr/scf			0.1201 to 0.3924[d]	0.77[e]
lb/hr				2180[f]
ESP control efficiency, %	98.0[g]			
Allowable emissions,				
gr/scf				0.014 (calc.)
lb/hr				39.7
At ESP Outlet				
SO_2 emission, ppm				5400[h]
lb/hr				17820
SO_3 emissions, ppm				15.9[i]
lb/hr				66.1
CO_2, volume percent				4.03
O_2, volume percent				14.17
H_2O, volume percent				8.70

Table 1 (Cont'd). SUMMARY OF PARTICULATE EMISSION DATA FOR EXISTING ELECTROSTATIC PRECIPITATOR ON REVERBERATORY FURNACE - MAGMA COPPER COMPANY, SAN MANUEL, ARIZONA

Item	Design (1)[a]	Actual (1)	Compliance tests conducted by company (2) October 30 and 31, 1975	EPA compliance tests by NEIC May 14 to 18, 1976 (3)
Metal analysis, lb/hr				
Tin (Sn)[j]				0.16
Arsenic (As)				5.2
Cadmium (Cd)				0.25
Chromium (Cr)				0.10
Copper (Cu)				9.8
Lead (Pb)				3.4
Mercury (Hg)				0.06
Molybdenum (MO)				0.81
Nickel (Ni)				0.03
Selenium (Se)				1.3
Vanadium (V)				
Zinc (Zn)				5.2[k]

[a] Numbers in parenthesis represent corresponding reference listed.

[b] Average of four compliance test runs conducted by Magma on October 30 and 31, 1975. Included in Appendix A, Magma Petition for Revision Table 1, page 4. NEIC report.

[c] Average of three compliance tests conducted by NEIC from May 14-22, 1976. The actual flow rates were 345,000, 313,000, and 328,300 scfm, respectively.

[d] Actual emissions during four compliance tests conducted by Magma on October 30 and 31, 1975 were 0.3268, 0.2202, 0.1201, and 0.3924 gr/scf, respectively. Isokinetic conditions were not met during all the tests.

[e] Average of three test runs (0.71, 0.85, and 0.71 gr/scf) conducted.

[f] Actual emissions during the three tests were 2090, 2450, and 2000 lb/hr.

[g] Based on instack filter tests.

[h] Average of three test runs. Actual measurements were 4500, 6670, and 5030 ppm, respectively.

[i] Average of three test runs. Actual measurements were 12.8, 16.2, and 18.7 ppm, respectively.

[j] Metals identified in particulates collected by EPA method 5 in ESP outlet during the second compliance test run.

[k] Filter zinc results are questionable.

Table 1 (Cont'd). SUMMARY OF PARTICULATE EMISSION DATA FOR EXISTING ELECTROSTATIC PRECIPITATOR ON REVERBERATORY FURNACE - MAGMA COPPER COMPANY, SAN MANUEL, ARIZONA

Reference

(1) State Implementation Plan Inspection of San Manuel Division Smelter, Magma Copper Company, San Manuel, Arizona. June 1976. In: Emission Testing at the Magma Copper Company Smelter, San Manuel, Arizona, by National Enforcement Investigations Center. EPA-330/2-76-029. May 2-22, 1976.

(2) Appendix A, Magma Petition for Revision In: Emission Testing at the Magma Copper Company Smelter, San Manuel, Arizona, by National Enforcement Investigations Center. EPA-330/2-76-029. May 2-22, 1976.

(3) Test Results: In: Emission Testing at the Magma Copper Company Smelter, San Manuel, Arizona, by National Enforcement Investigations Center. EPA 330/2-76-029. May 12-22, 1976.

future gas flow conditions of 641,200 acfm. This ductwork shall be rectangular in crosssection, fabricated of 1/4-inch-thick (minimum) steel plate consistent with the acidity of the gas stream, and be equipped with suitably reinforced stiffeners. An expansion joint in both the vertical and horizontal portions of this ductwork shall be provided. Any right-angle turns in this ductwork shall be of the largest centerline radius possible and designed to minimize pressure drop. The interface between the throat of the right-angle turn and the gathering plenum shall be designed to minimize any particulate material buildup. Turning vanes will be installed to streamline the flow where required. Flue shall also be tapered so as to minimize the entry pressure loss.

3. Outlets from the gathering flue to the nozzles of the control system shall be optimized and designed to provide uniform distribution of flow to the inlet nozzles, with a minimum pressure drop required to achieve this optimization. Each outlet shall also include an air-lock damper at the inlet nozzle to the add-on control equipment and all necessary platforms, headframes, and hoists required for operation of the air-lock dampers.

4. Expansion joints shall be provided at the interface of the inlet nozzles and the gathering plenum outlets.

5. Gas sampling stations and access platforms shall be provided at points designated by the EPA method of testing (at system inlet and outlet).

CONTROL SYSTEM SUPPORT STRUCTURE

The add-on control equipment support structure shall be provided complete with access and stairway landings. Structural elements required to support the add-on control equipment, access walkways, and stairways should be designed to provide clearance for any roadways or railroad equipment that must continue to operate during construction and after completion of the project.

ADD-ON CONTROL EQUIPMENT:

Electrostatic Precipitators: Dry Type (Sketch A-1)

1. The electrostatic precipitators will be horizontal-flow, plate-type of heavy-duty construction and shall be sectionalized and compartmentized for flexibility. Two separate inlet and outlet nozzles are to be provided to make each compartment isolated from the other one.

2. Mild-steel, high-voltage insulator compartments are to be provided. These compartments are to be

insulated and heated by hot-air, positive pressure blower systems utilizing electric heating and inlet air filtering.

3. Access doors and internal walkways between electrical sections will be provided.
4. All access openings will be provided with an automatic key interlock system to protect personnel and equipment. Structural and component design will provide allowance for free expansion so as to prevent permanent structure deformation at continuous gas operating temperatures of 600°F.
5. The precipitator housing is to be able to withstand the maximum internal negative pressure that might be created in operation.

PRECIPITATOR CASING

1. The precipitator casing will be of steel plate construction properly reinforced to withstand the acidity of the gas stream. Materials will meet specifications as described in the latest edition of the ASTM Standards.
2. Inlet and outlet nozzles to precipitator are to be provided by the contractor. Each nozzle will include necessary internal supports, guide vanes, distribution plates and appropriately located U

tube and sample ports. Flanges for attaching flues are to be included.

3. Casing and nozzles will be fabricated from steel plate.

HOPPERS

1. Dust hoppers will be located under the collecting sections and shall be V-shaped trough or bunker type.
2. Hoppers will be constructed of steel plate with a minimum thickness of 1/4 inch and to withstand the acidity of the gas stream.
3. Hoppers will be welded construction, having a minimum slope of 60°.
4. Each hopper will be provided with a 15" x 15" x 1" manual impact plate spaced at 3-foot centers along both sides of hoppers at accessible locations. Impact plate and poke holes are to be combined.
5. Provisions shall be made with double "Plattco" type valves or equivalent to prevent infiltration of air through the screw conveyors to the gas stream.
6. Screw conveyors shall be provided beneath all precipitator hoppers. Conveyors shall be sized and powered to handle expected dust loading, but

in no case shall they be less than 12 inches in diameter or have less than 7-1/2 horsepower drives.

RAPPERS

1. Rappers are to be of the electromagnetic or drop-hammer type with a heavy rapping force.

KEY INTERLOCKS

1. Key interlocks, to deenergize the unit, will be of lock and key type to protect operating personnel from high-voltage electrical equipment. Interlocks will be provided for the power panel, high-voltage switches, rectifier-transformer sets, and all access doors in the shell, housing, and hoppers that provide entrance into the electrodes in the high-voltage connections.

ELECTRODES

1. Collecting plate electrodes are to be minimum 16/18 gauge steel and designed to provide minimum reentrainment of dust by gas stream during rapping periods to be compatible with the acidity of the gas stream.
2. Discharge wires or solid electrodes will be held in place parallel to and at equal distances from the collecting plates by structural steel frames hanging from high-voltage, with isostatically

pressed alumina or equivalent support insulators located in the shell roof.

3. Approximate spacing between collecting plates will be 9 inches.

RECTIFIER-TRANSFORMER SETS

1. Each precipitator field will be supplied with its own separately controlled rectifier-transformer set.

2. The selenium rectifier-transformers will be 50% oversized, have adequate surge protection, and will be the oil-emersed, self-cool type.

3. The rectifier-transformer will be capable of half-wave or full-wave power by way of the associated switch.

4. Other accessories should include automatic controller, and meters for primary current, primary voltage, secondary current, and secondary voltage.

PRECIPITATOR DISCHARGE FLUE

1. The precipitator discharge flue shall begin at the outlet nozzle flange of the precipitators and terminate at the interface of this flue with the same point of discharge now used by the hot electrostatic precipitator.

2. A manually operated poised-blade louver damper shall be installed at the outlet nozzle flanges of

each precipitator. Damper and operating mechanism shall be fabricated of type 316 stainless steel and shall have a minimum-leakage characteristic.

3. An air-lock damper and an expansion joint shall be installed between the flow-control damper and the main flue on each of the two precipitator outlets, along with all necessary platforms.
4. Gas sampling stations and access platforms shall be provided at points designated by EPA Method 5 testing.
5. Structural elements required to support the discharge flue, access walkways and stairways shall be designed to provide clearance for railway equipment that must continue to operate during construction and after completion of the project.
6. Expansion joints shall be provided as required to prevent permanent structural deformations from occuring at a continuous operating temperature of 600°F.

PRECIPITATOR REDUNDANCY

1. The precipitation equipment shall be designed so that guarantee is met with one full width electrical field out of service.
2. The precipitation equipment shall be sized with a confidence level of at least 90 percent when all fields are in service.

Electrostatic Precipitator: Wet Type (Sketch A-2 & A-3)

See attached Sketch A-7 for the wet electrostatic precipitator circuitry.

The portions of the specification for the dry electrostatic precipitator that are applicable to the wet electrostatic precipitator shall apply.

The following factors shall be included:

1. Materials of construction shall withstand the corrosive atmosphere of acidity present in the gas stream.
2.* Heavy rapping forces are required, 50 "g's" or greater and continuous cleaning. (Lead and zinc in the discharge stream can form lead or zinc oxides that tend to destroy the cleaning capability of inlet field of the precipitator, therefore the necessity of continuous cleaning; zinc will galvanize to the collecting surfaces and thus the requirement for heavy rapping.)
3. If the wet ESP system as shown in Sketch A-7 is quoted as a complete system with hold tank, pH control, clarifier, vacuum filtration, pumps, etc., identify the major materials of construction, gpm, and estimated sludge discharge (in gpm) to the pond.

---

* not applicable

4. If the wet ESP system as shown in Sketch A-3 consists of only the electrostatic precipitator, indicate the gpm of water required, the number of nozzles for water sprays being supplied, and the head in inches of water required at the point of discharge into the precipitator. Also the estimated gpm discharged from the hoppers of the wet electrostatic gravity and the gpm of make-up water required.

5. As shown in Sketch A-2, a cooling chamber ahead of the wet-electrostatic precipitator would cool the gas to 250°F (±25°F) prior to its entry into the wet electrostatic precipitator.

6. As shown in Sketch A-3, the wet electrostatic precipitator receiving a gas stream at approximately 600°F would discharge the cleaned and cooled gas stream at 250°F (±25°F).

7. The removal efficiency required would be 98.2%.

COOLING CHAMBERS: (Sketch A-1, A-2, A-4, A-6)

Supply a complete system consisting of but not limited to the following: two cooling chambers of the downflow type and dry bottom design with a water filtration and pumping system, automatic apparatus for control of exit temperature, and all necessary piping, insulation, etc. Also supply the supports and ductwork, with insulation, to convey the cooled gases at 250°F (±25°F) from the discharge of the cooling tower to the precipitator. The chamber will have clean-out doors permitting man-entry and front-end unloaders for clean-up purposes.

The water system will be a closed-loop type. The materials of construction shall be compatible with the corrosive atmosphere of the gases.

Foundations will be by others.

VENTURI SCRUBBER: (Sketch A-5)

Supply a complete system consisting of but not limited to the following: one venturi scrubber with a holding tank, pumps, piping, variable-throat control, pH control, clarifier, vacuum filtration, flocculant additive system, structural supports, walkways, platforms, insulation, valving, ductwork as required, demister, etc. The pressure drop will be suggested by bidder. The materials of a construction shall be compatible with the corrosive atmosphere of the gases.

The water system will be a closed-loop type.

The materials of construction shall be compatible with the corrosive atmosphere of the gases.

Foundations will be by others.

FABRIC FILTER BAGHOUSE: (Sketch A-6)

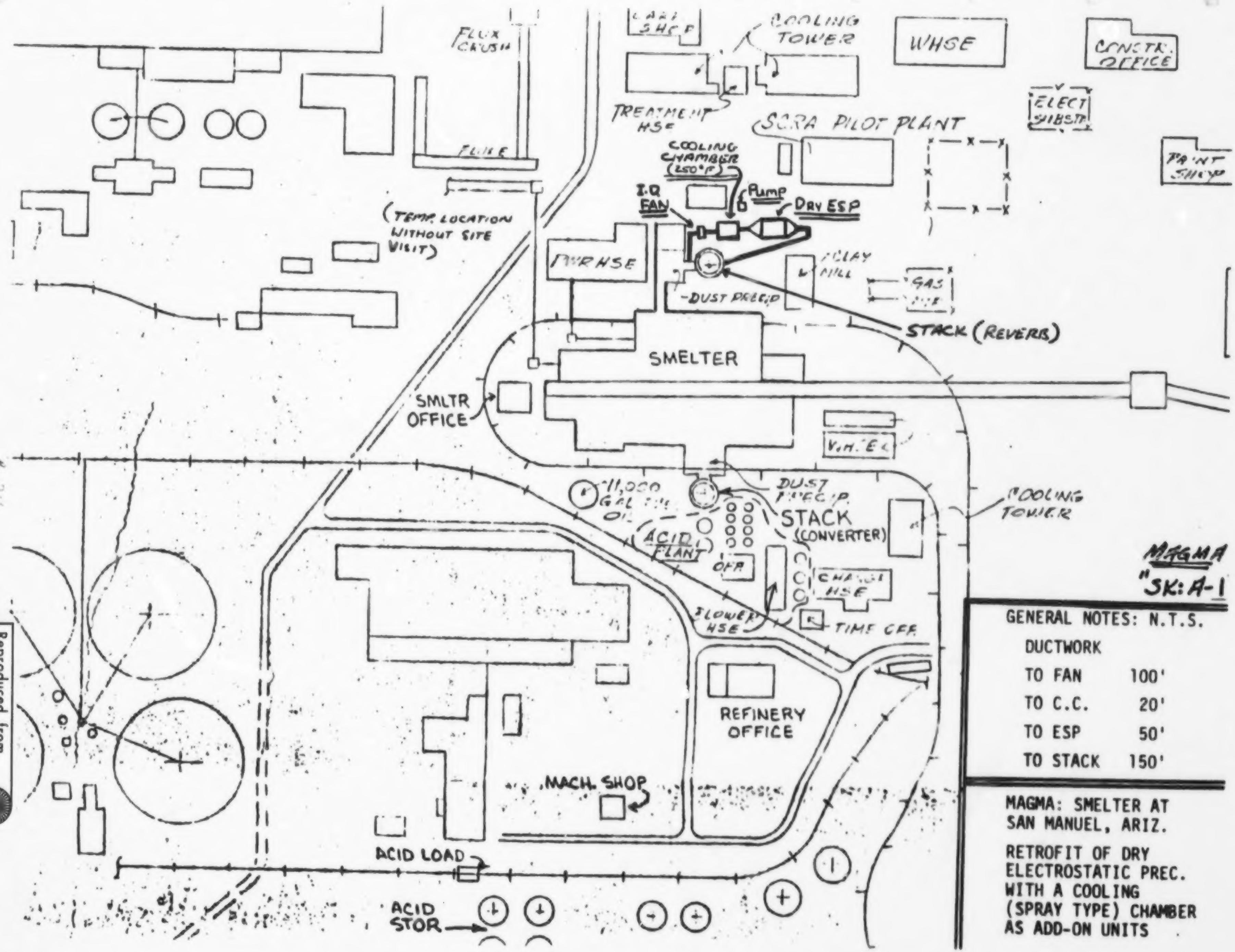
Supply a complete system consisting of but not limited to the following: one fabric filter (pulse-jet type, etc. will be left to the discretion of the vendor), baghouse, readily changeable bags, clean-out doors for interior cleaning of collectors and inspection; cooling chamber, pumps, etc. The bags and materials of construction shall be compatible with the acidity of the treated gases.

GENERAL DESIGN COMMENTS

1. All systems will be tabulated and broken down into major components, i.e., electrostatic precipitator, ductwork, structural steel, controls, (electrical, etc.) with their erected costs.
2. Each major piece of equipment (i.e., electrostatic precipitator, baghouse, etc.) will be reported as to square feet of collection area, number of fields, rapping force, type of electrodes, materials of construction, total weight in tons, size, height, duct size, number of bags, size, type, etc.).
3. Annual operating costs with quantities of electricity, water, etc. used; operating manpower, maintenance manpower, and costs; estimated life of the control equipment.

4. Equipment shall be in conformance with the National Electrical Code, OSHA, Federal, State, and local regulations.
5. Satisfactory performance tests will be as indicated in the dry electrostatic precipitator.

SKETCHES


FLUX CRUSH
FLUE
CARP SHOP
COOLING TOWER
TREATMENT HSE
WHSE
CONSTR. OFFICE
ELECT SUBSTA
SCRA PILOT PLANT
PAINT SHOP
COOLING CHAMBER (250°F)
PUMP
DRY ESP
I.D FAN
(TEMP. LOCATION WITHOUT SITE VISIT)
PWR HSE
CLAY MILL
GAS
DUST PRECIP
STACK (REVERB)
SMELTER
SMLTR OFFICE
11,000 GAL OIL
DUST PRECIP
STACK (CONVERTER)
ACID PLANT
OFR
CHANGE HSE
BLOWER HSE
TIME OFF
COOLING TOWER
REFINERY OFFICE
MACH. SHOP
ACID LOAD
ACID STOR

MAGMA
"SK: A-1

GENERAL NOTES: N.T.S.

DUCTWORK	
TO FAN	100'
TO C.C.	20'
TO ESP	50'
TO STACK	150'

MAGMA: SMELTER AT
SAN MANUEL, ARIZ.

RETROFIT OF DRY
ELECTROSTATIC PREC.
WITH A COOLING
(SPRAY TYPE) CHAMBER
AS ADD-ON UNITS

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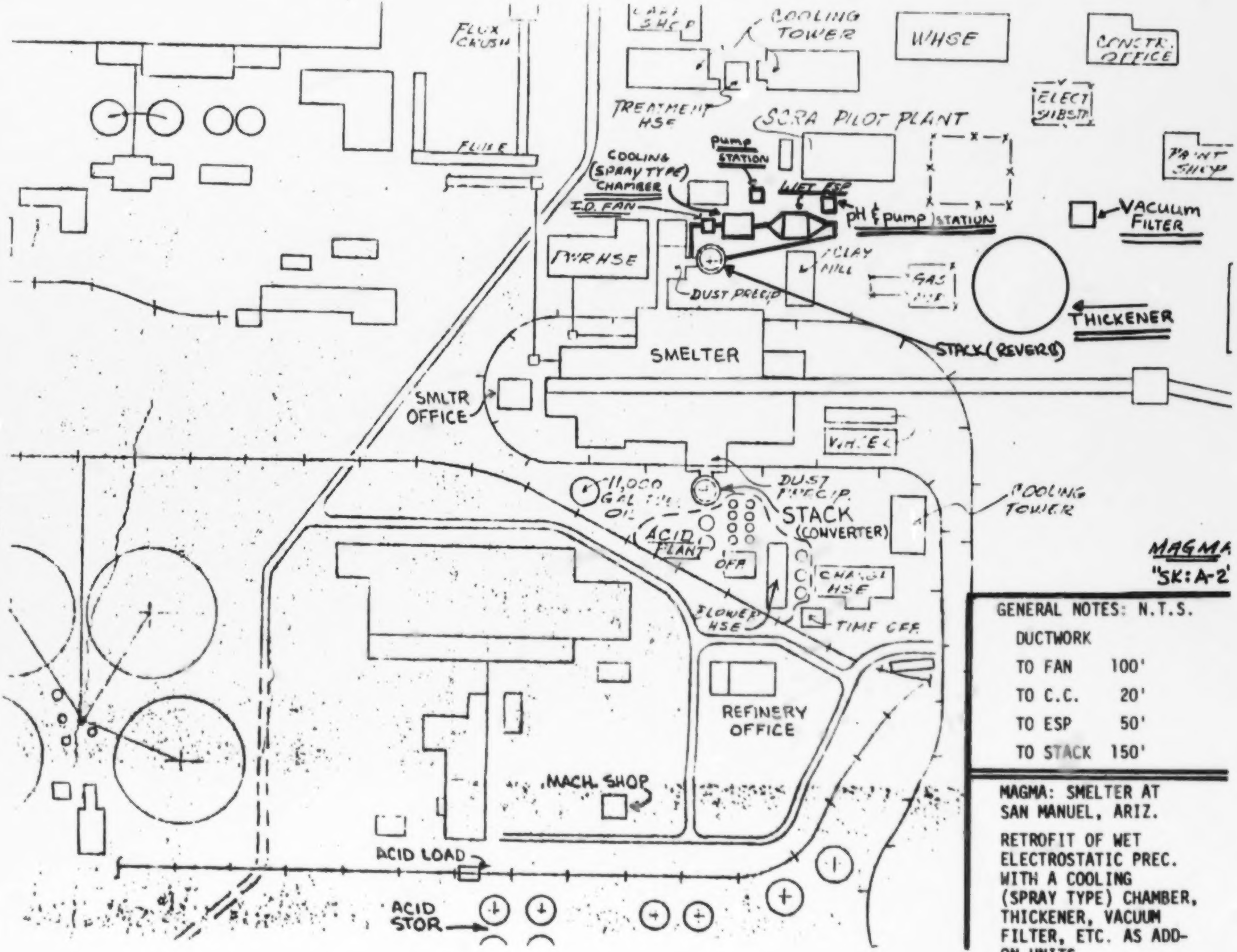

FLUX CRUSH
CAST SHOP
COOLING TOWER
WHSE
CONSTR. OFFICE
ELECT SUBSTN
TREATMENT HSE
SCRA PILOT PLANT
PAINT SHOP
FLUME
pump STATION
COOLING (SPRAY TYPE) CHAMBER
WET ESP
I.D. FAN
pH & pump STATION
VACUUM FILTER
PWR HSE
CLAY MILL
GAS
DUST PRECIP
THICKENER
SMELTER
STACK (REVERB)
SMLTR OFFICE
V.H.E.L
11,000 GAL FUEL OIL
DUST PRECIP.
STACK (CONVERTER)
COOLING TOWER
ACID PLANT
OFF.
CHANGE HSE
BLOWER HSE
TIME OFF.
REFINERY OFFICE
MACH. SHOP
ACID LOAD
ACID STOR

MAGMA

"SK:A-2"

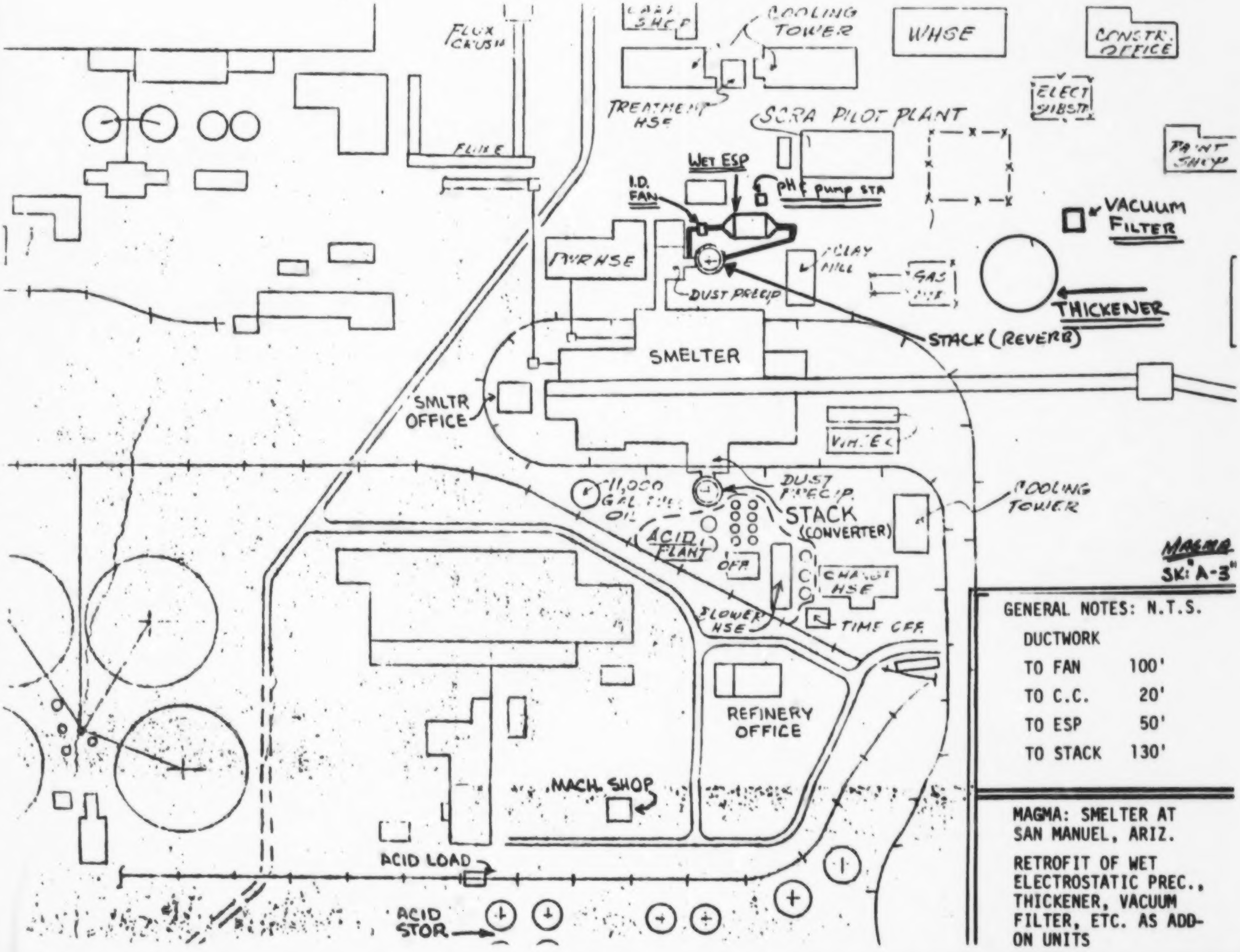
GENERAL NOTES: N.T.S.

DUCTWORK

TO FAN	100'
TO C.C.	20'
TO ESP	50'
TO STACK	150'

MAGMA: SMELTER AT SAN MANUEL, ARIZ.

RETROFIT OF WET ELECTROSTATIC PREC. WITH A COOLING (SPRAY TYPE) CHAMBER, THICKENER, VACUUM FILTER, ETC. AS ADD-ON UNITS


CARP SHOP
COOLING TOWER
WHSE
CONSTR. OFFICE
FLUX CRUSH
FLUME
TREATMENT HSE
SCRA PILOT PLANT
ELECT SUBSTA
PAINT SHOP
WET ESP
I.D. FAN
pH & pump STA
VACUUM FILTER
PWR HSE
DUST PRECIP
CLAY MILL
GAS
THICKENER
STACK (REVERB)
SMELTER
SMLTR OFFICE
V.M. EL
11,000 GAL FUEL OIL
DUST PRECIP.
STACK (CONVERTER)
COOLING TOWER
ACID PLANT
OFF.
CHANGE HSE
BLOWER HSE
TIME OFF.
REFINERY OFFICE
MACH. SHOP
ACID LOAD
ACID STOR

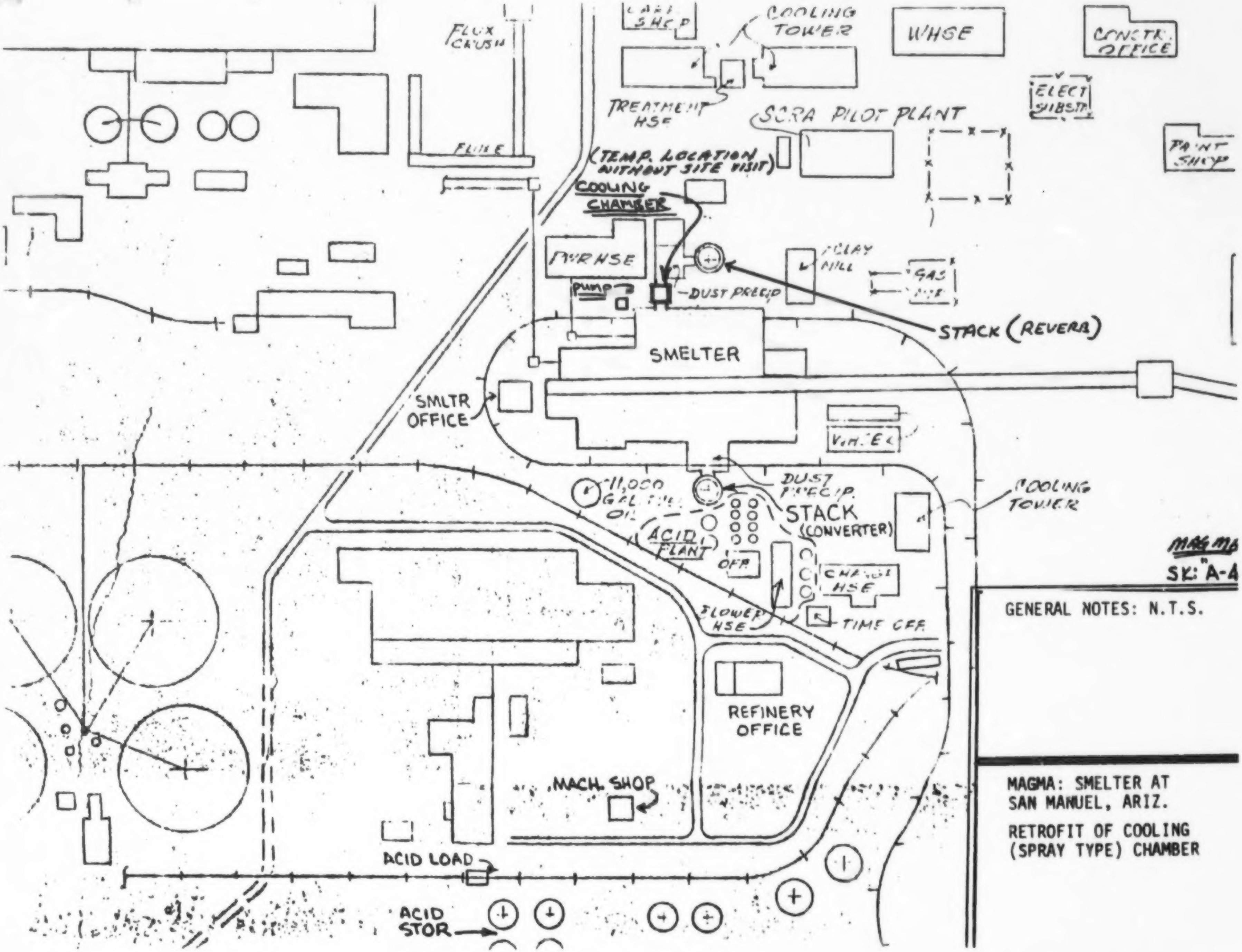
MAGMA SK: A-3"

GENERAL NOTES: N.T.S.

DUCTWORK	
TO FAN	100'
TO C.C.	20'
TO ESP	50'
TO STACK	130'

MAGMA: SMELTER AT SAN MANUEL, ARIZ.

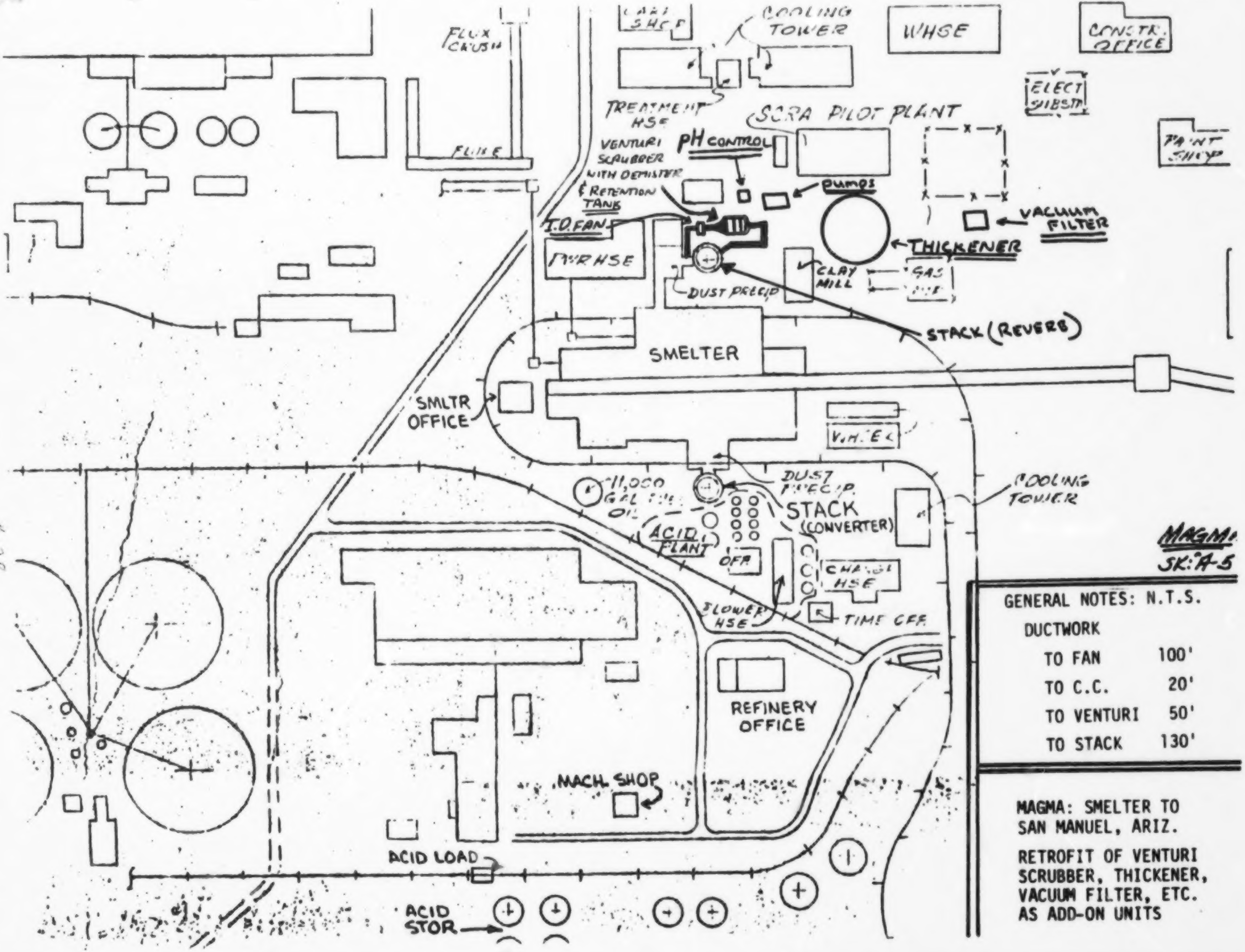
RETROFIT OF WET ELECTROSTATIC PREC., THICKENER, VACUUM FILTER, ETC. AS ADD-ON UNITS


CARP SHOP
COOLING TOWER
WHSE
CONSTR. OFFICE
ELECT SUBSTN
FLUX CRUSH
TREATMENT HSE
SCRA PILOT PLANT
PAINT SHOP
FLUME
(TEMP. LOCATION WITHOUT SITE VISIT)
COOLING CHAMBER
PWR HSE
CLAY MILL
GAS
PUMP
DUST PRECIP
STACK (REVERB)
SMELTER
SMLTR OFFICE
COOLING TOWER
DUST PRECIP.
11,000 GAL FUEL OIL
STACK (CONVERTER)
ACID PLANT
OFR
CHANGE HSE
BLOWER HSE
TIME OFF.
REFINERY OFFICE
MACH. SHOP
ACID LOAD
ACID STOR
MAGMA
SK: "A-4

GENERAL NOTES: N.T.S.

MAGMA: SMELTER AT
SAN MANUEL, ARIZ.

RETROFIT OF COOLING
(SPRAY TYPE) CHAMBER

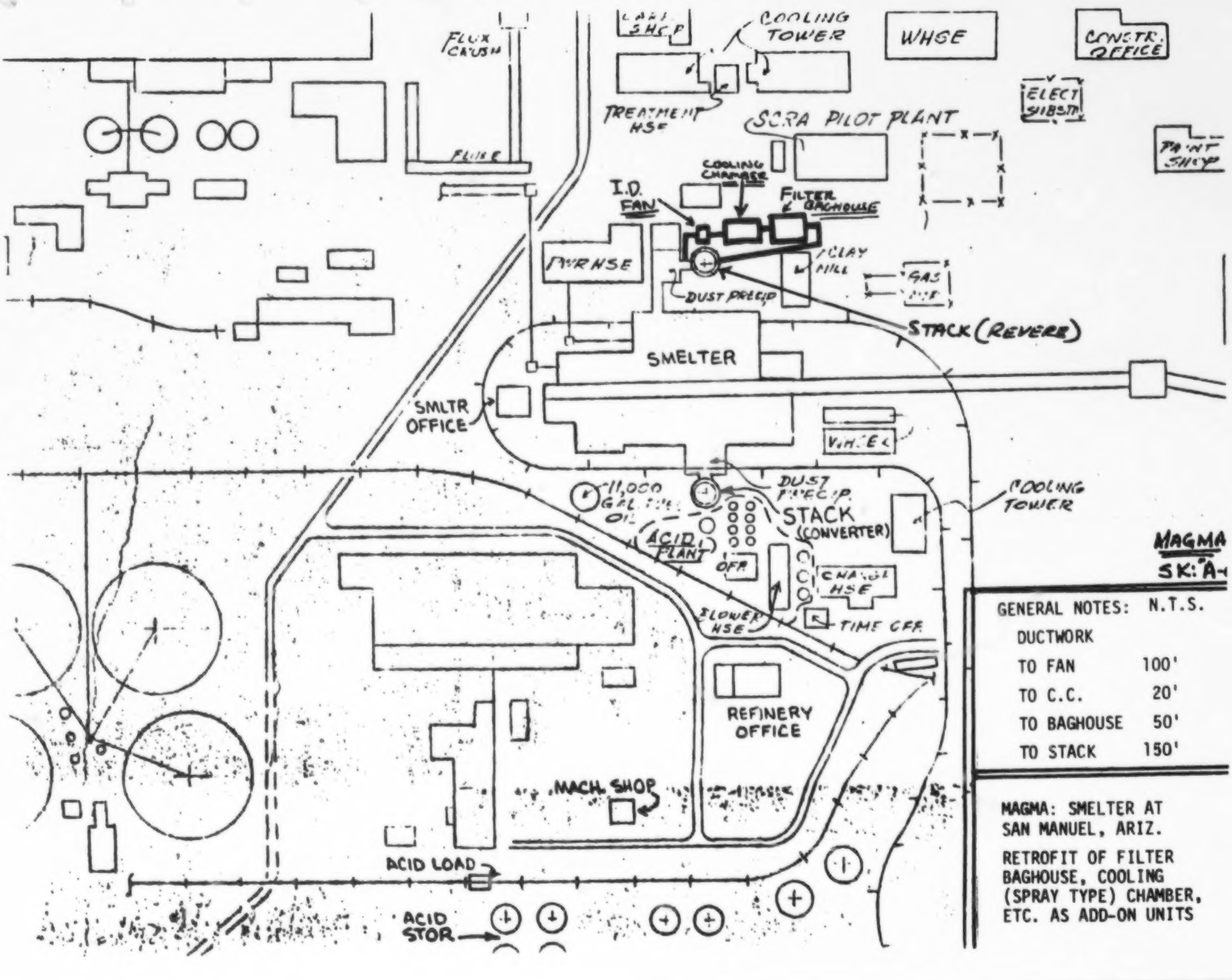

FLUX CRUSH
FLUX
CAR SHOP
COOLING TOWER
WHSE
CONSTR. OFFICE
ELECT SUBSTN
PAINT SHOP
TREATMENT HSE
SCRA PILOT PLANT
VENTURI SCRUBBER WITH DEMISTER & RETENTION TANK
PH CONTROL
PUMPS
VACUUM FILTER
THICKENER
I.D. FAN
PWR HSE
DUST PRECIP
CLAY MILL
GAS
STACK (REVERB)
SMELTER
SMLTR OFFICE
V.H. EL
DUST PRECIP.
STACK (CONVERTER)
COOLING TOWER
11,000 GAL OIL
ACID PLANT
OFR
CHANGE HSE
BLOWER HSE
TIME OFF
REFINERY OFFICE
MACH. SHOP
ACID LOAD
ACID STOR
MAGMA
SK:A-5

GENERAL NOTES: N.T.S.

DUCTWORK	
TO FAN	100'
TO C.C.	20'
TO VENTURI	50'
TO STACK	130'

MAGMA: SMELTER TO
SAN MANUEL, ARIZ.

RETROFIT OF VENTURI
SCRUBBER, THICKENER,
VACUUM FILTER, ETC.
AS ADD-ON UNITS


FLUX CRUSH
FLUXE
COOLING TOWER
WHSE
CONSTR. OFFICE
TREATMENT HSE
ELECT SUBSTN
SCRA PILOT PLANT
PAINT SHOP
COOLING CHAMBER
FILTER & BAGHOUSE
I.D. FAN
PWR HSE
CLAY MILL
GAS
DUST PRECIP
STACK (REVERB)
SMELTER
SMLTR OFFICE
COOLING TOWER
11,000 GAL OIL
DUST PRECIP.
STACK (CONVERTER)
ACID PLANT
OFF
CHANGE HSE
BLOWER HSE
TIME OFF.
REFINERY OFFICE
MACH. SHOP
ACID LOAD
ACID STOR

MAGMA
SK: A-

GENERAL NOTES: N.T.S.

DUCTWORK	
TO FAN	100'
TO C.C.	20'
TO BAGHOUSE	50'
TO STACK	150'

MAGMA: SMELTER AT SAN MANUEL, ARIZ.

RETROFIT OF FILTER BAGHOUSE, COOLING (SPRAY TYPE) CHAMBER, ETC. AS ADD-ON UNITS

APPENDIX C

PEDCo ENVIRONMENTAL
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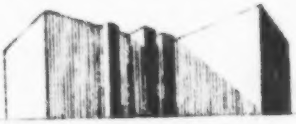
TECHNICAL SPECIFICATIONS FOR ADD-ON CONTROL SYSTEMS FOR REVERBERATORY FURNACE AT PHELPS DODGE COPPER COMPANY, AJO, ARIZONA

Prepared by

PEDCo Environmental, Inc.
11499 Chester Road
Cincinnati, Ohio 45246

PEDCo Project Number: 3287-B

June 28, 1977



CHESTER TOWERS

BRANCH OFFICES

Crown Center
Kansas City, Mo.

Professional Village
Chapel Hill, N.C.

C-i-a

TABLE OF CONTENTS

Page

SCOPE OF WORK 1

GENERAL INFORMATION 3

DESIGN CRITERIA AND GUARANTEE 3

SPECIFIC OPERATING CONDITIONS FOR ADD-ON EQUIPMENT 5

DESIGN LOADS 6

CONTROL SYSTEM SUPPORT STRUCTURE 12

    ADD-ON CONTROL EQUIPMENT: ELECTROSTATIC PRECIPITATOR, DRY TYPE 12

    ADD-ON CONTROL EQUIPMENT: ELECTROSTATIC PRECIPITATOR, WET TYPE 18

    ADD-ON CONTROL EQUIPMENT: COOLING CHAMBERS 19

    ADD-ON CONTROL EQUIPMENT: VENTURI SCRUBBER 20

    ADD-ON CONTROL EQUIPMENT: FABRIC FILTER BAGHOUSE 20

SKETCHES A-1

LIST OF TABLES

No. Page

1 Summary of Electrostatic Precipitator Design Parameters and Operating Data at Phelps Dodge Copper Company, Ajo, Arizona 7

LIST OF SKETCHES

No.		Page
A-1	Dry Electrostatic Precipitator	A-1
A-2	Wet Electrostatic Precipitator/Cooling Chamber	A-2
A-3	Wet Electrostatic Precipitator	A-3
A-4	Cooling Chamber	A-4
A-5	Venturi Scrubber	A-5
A-6	Fabric Filter Baghouse	A-6

TECHNICAL SPECIFICATIONS (COPPER SMELTER)

It is the intent of these specifications to provide the contractor with sufficient information to furnish and install gas-cleaning systems, including the control equipment to treat exhaust gases from an already-installed electrostatic precipitator on a copper concentrate smelting reverberatory furnace at the Phelps Dodge plant at Ajo, Arizona.

SCOPE OF WORK

Major items of work to be accomplished by contractor consist of the following:

1. Engineer, design, procure materials and equipment, fabricate, and erect from ground level from the discharge of the existing hot electrostatic precipitator flue to the inlet nozzles of the required add-on control equipment. The contractor shall provide heat insulation on flues.
2. Engineer, design, procure materials and equipment, fabricate, and erect from ground level up the required support structure for the add-on control equipment, including all required walkways, stairways, and handrails. The supporting structure system will exclude foundations, which will be supplied and furnished by others.

3. Engineer, design, procure materials and equipment, fabricate, and deliver add-on control equipment, complete with all electrical equipment required to place the unit into operation.
4. Erect the add-on control equipment, including furnishing and installing heat insulation on the add-on control equipment where required. The erection portion excludes furnishing wire and conduit or a control room for electrical equipment.
5. Engineer, design, procure materials and equipment, fabricate, and erect from ground level up the discharge flues starting at the outlet nozzle flange of the add-on control equipment and terminating at the present discharge to the ducting utilized by the existing hot electrostatic precipitator.
6. Provide qualified personnel for the initial start-up of the complete system. Start-up is to include all testing, adjustments, and modifications necessary to ensure proper operation of the units at or above the collection efficiency levels specified herein. Start-up is also to include the training of owner's operating and maintenance personnel to operate and maintain the equipment.

7. The contractor shall provide the services of a qualified Field Erection Engineer who shall give supervision and technical assistance as required during assembly, field erection, and start-up of the equipment.

8. The contractor will furnish a test model of the add-on control equipment and the flue systems for gas-flow study.

GENERAL INFORMATION

An additional fan to handle the pressure drop shall be included with any add-on control equipment.

All electrical, water, and other services will be within 100 feet of the new facilities.

Site leveling and preparation by others.

The units are to operate 24 hours per day, 365 days per year.

The layouts for particulate removal control system are shown on attached Sketches A-1 through A-6. The length of duct runs are shown on the sketches.

DESIGN CRITERIA AND GUARANTEE

1. Collection Efficiency

The add-on control equipment will have a minimum guaranteed collection efficiency of 93 percent by weight of the entering particulate matter as determined by EPA Test Method 5, with a filter temperature of 250°F.

2. Efficiency Tests

The owner shall make regular tests to check the collecting efficiency. The contractor and owner shall jointly test the add-on control equipment for collection efficiency immediately after completion of all construction, at 6 months and at 11 months after completion. The test at 11 months will determine the guarantee performance.

3. Efficiency Curves

The contractor shall furnish with its proposal expected efficiency curves, showing the guarantee point. Curves will show expected efficiency versus volume, grain loading, percent moisture, gas temperature, percent SO_3 in gas, percent lead, and any other significant parameters affecting efficiency of the add-on control equipment.

4. Draft Loss

The draft loss between inlet and outlet flanges of the nozzles will be held to a minimum to attain the removal efficiency required.

5. Gas Velocity

The gas velocity through the precipitator proper will not exceed 3 feet per second; and the velocity through a venturi scrubber or baghouse shall be recommended by the vendor.

6. Gas Flow Study

The contractor shall construct a test model of the system from and including the outlets of the waste heat boilers to the stack.

7. Redundancy

The control equipment shall be sized with a confidence level of at least 90 percent when the system is operating at a full mode.

SPECIFIC OPERATING CONDITIONS FOR ADD-ON CONTROL EQUIPMENT

The add-on control equipment will be capable of handling copper smelting reverberatory furnace exhaust gases described as follows:

1. Amount of gases per precipitator: 186,000 acfm.
2. Operating temperature of gases: 598°F.
3. Short-term temperature surges to 650°F during furnace charging periods.
4. Nominal dust particle inlet loading is 0.56 grain per SCF. Estimated dust particulate inlet loading is 1.37 grains per SCF during furnace charging periods.

5. Expected dust screen analysis mesh and percent: Not available.
6. Expected volumetric analysis of gas component and percent: See attached Table 1.
7. Estimated bulk density of collected dust, dry pounds per cubic foot: Not available.
8. Acid dew point of gas: Not available.
9. Expected composition of dust: Table 2 presents element analysis at existing electrostatic precipitator inlet and outlet.

DESIGN LOADS

This should include vertical live loads, lateral loads, and earthquake considerations.

FLUE SYSTEM:

1. The flue system shall begin at the outlet flange of the existing hot electrostatic precipitator and proceed to the inlet flanges of the add-on control equipment.
2. The ductwork from the outlet flange of the existing hot electrostatic precipitator to the add-on control equipment shall be sized for minimum gas velocity of 3500 feet per minute under maximum future gas-flow conditions of 186,000 acfm. This ductwork shall be rectangular in cross section, fabricated of 1/4-inch-thick (minimum) steel plate consistent with the acidity of the gas stream, and

Table 1. SUMMARY OF PARTICULATE EMISSION DATA FOR EXISTING ELECTROSTATIC PRECIPITATOR ON REVERBERATORY FURNACE - PHELPS DODGE COPPER SMELTER, AJO, ARIZONA

Item	Design (1)[a]	Actual (1)	Radian test results July 6-16, 1976 (2)	SRI test results July 9-10, 1976 (3)	Aerotherm test results July 15-30, 1976 (4)
ESP manufacturer	Joy Western				
ESP inlet conditions					
Velocity, fps	at 13.8 psia		55 to 57[b]		
Volume flow at continous rating, acfm	150,000[c]	164,000	160,000[d]		
scfm	75,000 (calc)		77,580 (calc)		
Temperature, °F	600 (max.)	450 to 550	633		
Gas dust loadings: by instack filter, gr/scf	2.25 (max.)[e]	0.592 (calc.)	avg. 0.6 (0.17 to 1.55)[e]		
lb/hr	1446.43 (calc max.)	421[e]	avg. 403 (calc)[f]		
by instack/outstack filter, gr/scf			1.56 to 2.47[g]		
lb/hr			1041 to 1648 (calc.)		
by EPA test method 5, gr/scf					
lb/hr					
ESP outlet conditions					
Velocity, fps			114		77.17
Volume flow at continuous rating, acfm			185,330		116,200[h]
scfm			92,840 (calc)		59,500 (calc)
Temperature, °F			598		550 to 600
Gas dust loadings: by instack filter, gr/scf	0.063	0.067 (calc)	0.02[i]		0.42 (calc)
lb/hr	40 (guaranteed)	47[j]	13.44 (calc)		212.8[k]

Table 1 (continued). SUMMARY OF PARTICULATE EMISSION DATA FOR EXISTING ELECTROSTATIC PRECIPITATOR ON REVERBERATORY FURNACE - PHELPS DODGE COPPER SMELTER, AJO, ARIZONA

Item	Design (1)[a]	Actual (1)	Radian test results July 6-16, 1976 (2)		SRI test results July 9-10, 1976 (3)	Aerotherm test results July 15-30, 1976 (4)
ESP outlet conditions (continued)						
by instack/outstack filter, gr/scf			0.84 to 1.37[l]			0.83 (calc.)
lb/hr			560 to 914 (calc.)			423.9[m]
by EPA test method 5, gr/scf						0.56 (calc.)
lb/hr						285.4[n]
ESP control efficiency, %	96.83[p]				96.7[q]	
Dust size analysis						
at ESP inlet					>10μm[r]	
at ESP outlet						
Gas composition, %			ESP[s] inlet	ESP[s] outlet		ESP[s] outlet
H_2O			13.2	12.3		12.2
O_2			10.7	9.5		13.6
CO_2			6.0	6.5		4.1
SO_2			0.33	0.56		8.1
SO_3			0.006	0.012		0.0034

Footnotes

[a] Numbers in parentheses represent corresponding references listed.

[b] Actual measurements in each of the two inlet ducts to the ESP were 55 and 57 fps, respectively.

[c] At 32°F and 14.7 psia.

[d] Average of six tests conducted on July 7 through July 10, 1976. During the test runs, the volume rate varies from 148,000 to 167,000 acfm.

[e] 1975 tests by Engineering Testing Laboratories, using WP Method 50, hard particulates only.

[e'] Result of five test runs conducted July 8 through July 10, 1976. Actual emissions varied from 0.17 to 1.55 gr/scf.

[f] According to Radian, the outlet sampling locations was much more favorable than the inlet and for this reason to gas flow rate obtained at the outlet 78,400 scfm was used to calculate the flow rates of gas through the ESP. Based on this gas flow rate and average loading of 0.6 gr/scf, Radian calculated a mass flow rate of 340 lb/hr.

[g] Results of two test runs performed at a single point in the one duct (two ducts lead into ESP). Test run 1 collected 0.58 gr/scf on instack filter and 1.89 gr/scf on outstack filter, and test run 2 collected 0.31 gr/scf on instack filter and 1.25 gr/scf on outstack filter.

[h] Average of 11 tests conducted July 20 to 30, 1976, during which the volume flow was between 46,700 and 70,000 scfm.

[i] Average of five test conducted on July 8 to 10, 1976. The minimum and maximum dust loadings obtained during the test were 0.017 and 0.025 gr/scf, respectively.

[j] 1975 tests by Engineering Testing Laboratories, using EPA method 5 with sulfates deducted.

[k] Average particulate collected on instack filter during two tests conducted by using instack/outstack filters on July 29 and 30, 1976. The actual readings were 217.2 and 208.4 lb/hr.

[l] Results of three test runs. The actual readings were 0.97, 0.84, and 1.37 gr/scf. Amounts collected on instack filters in these three test runs were 0.027, 0.072, and 0.019 gr/scf, respectively.

[m] Average of two test runs conducted on July 29 and 30, 1976. Actual readings were 423.0 and 423.9 lb/hr.

[n] Average of seven test runs during July 21-28, 1976. The minimum and maximum readings were 216.2 and 331.3 lb/hr, respectively.

[p] Guaranteed efficiency based on instack filter tests.

[q] Using instack filter method.

[r] Overall mass median diameter.

[s] Average of many measurements.

Table 2. ANALYSES OF TOTAL PARTICULATE (SOLID PHASE AND VAPOR PHASE PARTICULATE AT THE EXISTING ELECTROSTATIC PRECIPITATOR OUTLET (IN POUNDS PER HOUR)

Element	Total particulate (measured on 7/11/76)	Total particulate (measured on 7/13/76)	Vapor phase (measured on 7/16/76)
As	140	76	15
Ba	ND	0.64	0.27
Be	0.011	3.4×10^{-3}	$<4 \times 10^{-3}$
Cd	0.016	7.6	1.1×10^{-4}
Cr	0.011	0.044	0.036
Cu	1.0	18	2.94
F	7.5	9.4	11.0
Fe	-	0.55	0.196
Hg	5.6×10^{-3}	0.033	0.062
Mo	0.16	0.17	0.016
Ni	0.085	0.011	0.031
Pb	0.079	0.38	8.7×10^{-3}
Sb	0.33	0.030	3.0×10^{-3}
Se	0.97	0.65	0.21
V	0.062	0.027	0.020
Zn	0.082	0.22	0.036

[a] Existing ESP in operating at 598°F.

[b] In addition, 2210 lbs/hr of sulfur was collected as SO_2 and 50 lb/hr sulfur as SO_3.

(Radian Corporation conducted gas particulate sampling on the reverberatory furnace and its control system at Phelps-Dodge Copper Company during July 1976. During the sampling program, they measured the total particulate solid phase and vapor phase, present in the existing electrostatic precipitator outlet by using a wet electrostatic precipitate sampler in series with a set of impingers. They also measured only vapor phase particulate content of the gas at the existing ESP outlet by using a cyclone and filter to separate solid phase particulate of the gas, and a set of impingers in series to trap the vapor phase particulate. Table 2 presents analyses of total particulate and vapor phase particulate.)

be equipped with suitably reinforced stiffeners. An expansion joint in both the vertical and horizontal portions of this ductwork shall be provided. Any right-angle turns in this ductwork shall be of the largest centerline radius possible and designed to minimize pressure drop. The interface between the throat of the right-angle turn and the gathering plenum shall be designed to minimize any particulate material buildup. Turning vanes will be installed to streamline the flow where required. Flue shall also be tapered so as to minimize the entry pressure loss.

3. Outlets from the gathering flue to the nozzles of the control system shall be optimized and designed to provide uniform distribution of flow to the inlet nozzles, with a minimum pressure drop required to achieve this optimization. Each outlet shall also include an air-lock damper at the inlet nozzle to the add-on control equipment and all necessary platforms, headframes, and hoists required for operation of the air-lock dampers.
4. Expansion joints shall be provided at the interface of the inlet nozzles and the gathering plenum outlets.

5. Gas sampling stations and access platforms shall be provided at points designated by the EPA method of testing.

CONTROL SYSTEM SUPPORT STRUCTURE

The add-on control equipment support structure shall be provided complete with access and stairway landings. Structural elements required to support the add-on control equipment, access walkways, and stairways should be designed to provide clearance for any roadways or railroad equipment that must continue to operate during construction and after completion of the project.

ADD-ON CONTROL EQUIPMENT:

Electrostatic Precipitators: Dry Type (Sketch A-1)

1. The electrostatic precipitators will be horizontal-flow, plate-type of heavy-duty construction and shall be sectionalized and compartmentized for flexibility. Two separate inlet and outlet nozzles are to be provided to make each compartment isolated from the other one.
2. Mild-steel, high-voltage insulator compartments are to be provided. These compartments are to be insulated and heated by hot-air, positive-pressure blower systems utilizing electric heating and inlet air filtering.

3. Access doors and internal walkways between electrical sections will be provided.
4. All access openings will be provided with an automatic key interlock system to protect personnel and equipment. Structural and component design will provide allowance for free expansion so as to prevent permanent structure deformation from occurring at continuous gas operating temperatures of 600°F.
5. The precipitator housing is to be able to withstand the maximum internal negative pressure that might be created in operation.

PRECIPITATOR CASING

1. The precipitator casing will be of steel plate construction properly reinforced to withstand the acidity of the gas stream. Materials will meet specifications as described in the latest edition of the ASTM Standards.
2. Inlet and outlet nozzles to precipitator are to be provided by the contractor. Each nozzle will include necessary internal supports, guide vanes, distribution plates and appropriately located U tube and sample ports. Flanges for attaching flues are to be included.
3. Casing and nozzles will be fabricated from steel plate.

HOPPERS

1. Dust hoppers will be located under the collecting sections and shall be V-shaped trough or bunker type.
2. Hoppers will be constructed of steel plate with a minimum thickness of 1/4 inch and to withstand the acidity of the gas stream.
3. Hoppers will be welded construction, having a minimum slope of 60°.
4. Each hopper will be provided with a 15" x 15" x 1" manual impact plate spaced at 3-foot centers along both sides of hoppers at accessible locations. Impact plate and poke holes are to be combined.
5. Provisions shall be made with double "Plattco" type valves or equivalent to prevent infiltration of air through the screw conveyors to the gas stream.
6. Screw conveyors shall be provided beneath all precipitator hoppers. Conveyors shall be sized and powered to handle expected dust loading, but in no case shall they be less than 12 inches in diameter or have less than 7-1/2 horsepower drives.

RAPPERS

1. Rappers are to be of the electromagnetic or drop hammer type with a heavy rapping force.

KEY INTERLOCKS

1. Key interlocks, to deenergize the unit, will be of lock and key type to protect operating personnel from high-voltage electrical equipment. Interlocks will be provided for the power panel, high-voltage switches, rectifier-transformer sets, and all access doors in the shell, housing, and hoppers that provide entrance into the electrodes in the high-voltage connections.

ELECTRODES

1. Collecting plate electrodes are to be minimum 16/18 gauge steel and designed to provide minimum reentrainment of dust by gas stream during rapping periods to be compatible with the acidity of the gas stream.
2. Discharge wires or solid electrodes will be held in place parallel to and at equal distances from the collecting plates by structural steel frames hanging from high-voltage, with isostatically pressed alumina or equivalent support insulators located in the shell roof.

3. Approximate spacing between collecting plates will be 9 inches.

RECTIFIER-TRANSFORMER SETS

1. Each precipitator field will be supplied with its own separately controlled rectifier-transformer set.
2. The selenium rectifier-transformers will be 50% oversized, have adequate surge protection, and will be the oil-emersed, self-cool type.
3. The rectifier-transformer will be capable of half-wave or full-wave power by way of the associated switch.
4. Other accessories should include automatic controller, meters for primary current, primary voltage, secondary current and secondary voltage.

PRECIPITATOR DISCHARGE FLUE

1. The precipitator discharge flue shall begin at the outlet nozzle flange of the precipitators and terminate at the interface of this flue with the same point of discharge now used by the hot electrostatic precipitator.
2. A manually operated poised-blade louver damper shall be installed at the outlet nozzle flanges of each precipitator. Damper and operating mechanism shall be fabricated of type 316 stainless steel and shall have a minimum-leakage characteristic.

3. An air-lock damper and an expansion joint shall be installed between the flow-control damper and the main flue on each of the two precipitator outlets, along with all necessary platforms.
4. Gas sampling stations and access platforms shall be provided at points designated by EPA Method 5 testing.
5. Structural elements required to support the discharge flue, access walkways, and stairways shall be designed to provide clearance for railway equipment that must continue to operate during construction and after completion of the project.
6. Expansion joints shall be provided as required to prevent permanent structural deformations from occuring at a continuous operating temperature of 600°F.

PRECIPITATOR REDUNDANCY

1. The precipitation equipment shall be designed so that guarantee is met with one full-width electrical field out of service.
2. The precipitation equipment shall be sized with a confidence level of at least 90 percent when all fields are in service.

Electrostatic Precipitator: Wet Type (Sketch A-2 & A-3)

See attached Sketch A-7 for the wet electrostatic precipitator circuitry.

The portions of the specification for the dry electrostatic precipitator that are applicable to the wet electrostatic precipitator shall apply.

The following factors shall be included:

1. Materials of construction shall withstand the corrosive atmosphere of acidity present in the gas stream.
2. If the wet ESP system as shown in Sketch A-7 is quoted as a complete system with hold tank, pH control, clarifier, vacuum filtration, pumps, etc., identify the major materials of construction, gpm, and estimated sludge discharge (in gpm) to the pond.
3. If the wet ESP system as shown in Sketch A-3 consists of only the electrostatic precipitator, indicate the gpm of water required, the number of nozzles for water sprays being supplied, and the head in inches of water required at the point of discharge into the precipitator, amount of water required for flushing and water flushing frequency. Also the estimated gpm discharged from the hoppers

of the wet electrostatic gravity, and the gpm of make-up water required.

4. As shown in Sketch A-2, a cooling chamber ahead of the wet-electrostatic precipitator would cool the gas to 250°F (±25°F) prior to its entry into the wet electrostatic precipitator.

5. As shown in Sketch A-3, the wet electrostatic precipitator receiving a gas stream at approximately 600°F would discharge the cleaned and cooled gas stream at 250°F (±25°F).

6. The removal efficiency required would be 93%.

COOLING CHAMBERS: (Sketch A-1, A-2, A-4, A-6)

Supply a complete system consisting of but not limited to the following: two cooling chambers of the downflow type and dry bottom design with a water filtration and pumping system, automatic apparatus for control of exit temperature, and all necessary piping, insulation, etc. Also supply the supports and ductwork, with insulation, to convey the cooled gases at 250°F (±25°F) from the discharge of the cooling tower to the precipitator. The chamber will have clean-out doors permitting man-entry and front-end unloaders for clean-up purposes.

The water system will be a closed-loop type. The materials of construction shall be compatible with the corrosive atmosphere of the gases.

Foundations will be by others.

VENTURI SCRUBBER: (Sketch A-5)

Supply a complete system consisting of but not limited to the following: one venturi scrubber with a holding tank, pumps, piping, variable-throat control, pH control, clarifier, vacuum filtration, flocculant additive system, structural supports, walkways, platforms, insulation, valving, ductwork as required, demister, etc. The pressure drop will be suggested by the bidder. The materials of a construction shall be compatible with the corrosive atmosphere of the gases.

The water system will be a closed-loop type.

The materials of construction shall be compatible with the corrosive atmosphere of the gases.

Foundations will be by others.

FABRIC FILTER BAGHOUSE: (Sketch A-6)

Supply a complete system consisting of but not limited to the following: one fabric filter (pulse-jet type, etc. will be left to the discretion of the vendor), baghouse, readily changeable bags, clean-out doors for interior cleaning of collectors and inspection; cooling chambers, pumps, piping, etc. The bags and all materials of construction shall be compatible with the acidity of the treated gases. Temperature of gases to the baghouse will be 250°F (±25°F).

GENERAL DESIGN COMMENTS:

1. All systems will be tabulated and broken down into major components, i.e., electrostatic precipitator, ductwork, structural steel, controls (electrical, etc.) with their erected costs.
2. Each major piece of equipment (i.e., electrostatic precipitator, baghouse, etc.) will be reported as to square feet of collection area, number of fields, rapping force, type of electrodes, materials of construction, total weight in tons, size, height, duct size, number of bags, size, type, etc.).
3. Annual operating costs with quantities of electricity, water, etc. used; operating manpower, maintenance manpower and costs; estimated life of the control equipment.
4. Equipment shall be in conformance with the National Electrical Code, OSHA, Federal, State, and local regulations.
5. Satisfactory performance tests will be as indicated in the dry electrostatic precipitator.

SKETCHES

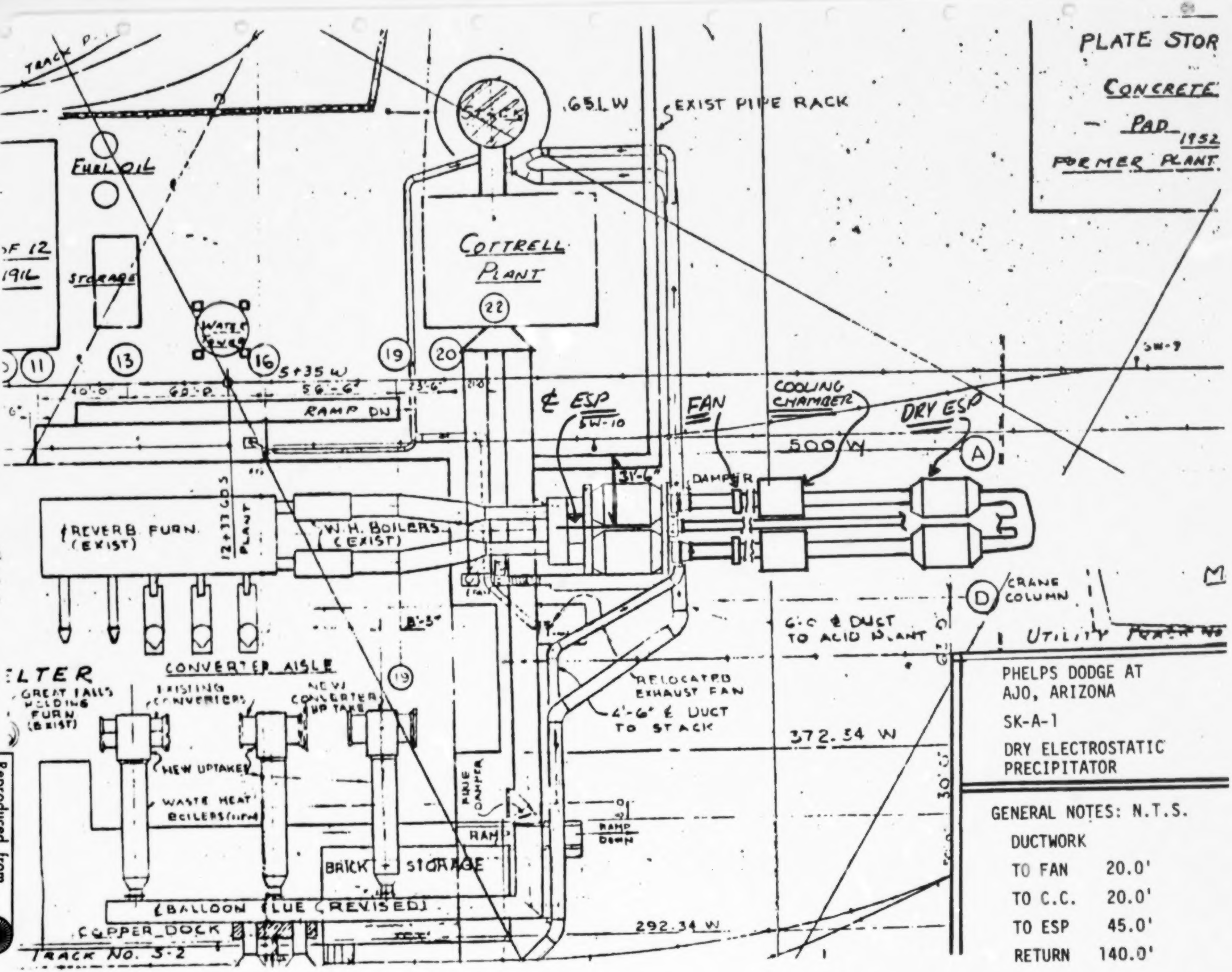


PLATE STOR
CONCRETE
– PAD 1952
FORMER PLANT
TRACK
FUEL OIL
STORAGE
OF 12
1916
COTTRELL PLANT
STACK
WATER TOWER
.65 L W
EXIST PIPE RACK
(22)
(20)
(19)
(16)
(13)
(11)
5+35 W
40'-0"
60'-0"
56'-6"
23'-6"
RAMP DN
℄ ESP
SW-10
FAN
DAMPER
COOLING CHAMBER
DRY ESP
500 W
SW-9
(A)
31'-6"
REVERB. FURN. (EXIST)
12+33 CDS PLANT
W.H. BOILERS (EXIST)
18'-3"
(D)
CRANE COLUMN
M
6'-0" ℄ DUCT TO ACID PLANT
UTILITY
ELTER
CONVERTER AISLE
GREAT FALLS HOLDING FURN (EXIST)
EXISTING CONVERTERS
NEW CONVERTER UPTAKE
NEW UPTAKES
WASTE HEAT BOILERS
RELOCATED EXHAUST FAN
4'-6" ℄ DUCT TO STACK
372.34 W
FLUE DAMPER
RAMP
RAMP DOWN
30'-0"
BRICK STORAGE
BALLOON FLUE (REVISED)
COPPER DOCK
TRACK NO. 5-2
292.34 W

PHELPS DODGE AT
AJO, ARIZONA

SK-A-1

DRY ELECTROSTATIC
PRECIPITATOR

GENERAL NOTES: N.T.S.

DUCTWORK

TO FAN	20.0'
TO C.C.	20.0'
TO ESP	45.0'
RETURN	140.0'

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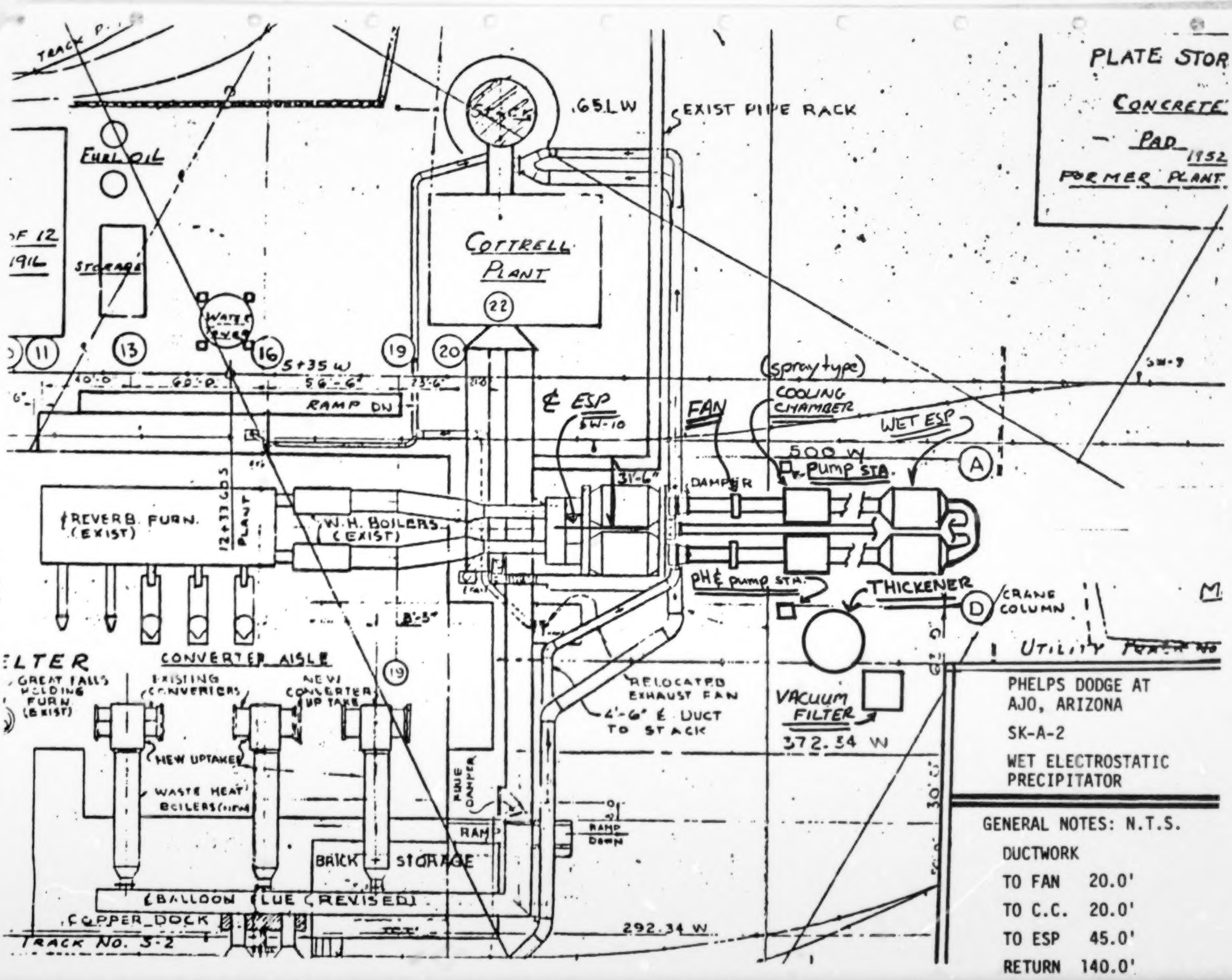


PLATE STOR
CONCRETE
– PAD 1952
FORMER PLANT
TRACK P
FUEL OIL
OF 12
1916
STORAGE
WATER TANK
.65LW
EXIST PIPE RACK
COTTRELL PLANT
22
11
13
16
19
20
5+35 W
40'-0"
60'-0"
56'-6"
23'-6"
RAMP DN
℄ ESP
SW-10
FAN
(spray type)
COOLING CHAMBER
WET ESP
500 W
PUMP STA.
DAMPER
A
SW-9
31'-6"
REVERB. FURN. (EXIST)
12+33 GDS PLANT
W.H. BOILERS (EXIST)
PH & pump STA.
THICKENER
D
CRANE COLUMN
M
UTILITY
8'-3"
ELTER
CONVERTER AISLE
GREAT FALLS HOLDING FURN. (EXIST)
EXISTING CONVERTERS
NEW CONVERTER UP TAKE
NEW UPTAKE
WASTE HEAT BOILERS
RELOCATED EXHAUST FAN
4'-6" ℄ DUCT TO STACK
VACUUM FILTER
372.34 W
FLUE DAMPER
RAMP
RAMP DOWN
BRICK STORAGE
(BALLOON FLUE (REVISED)
COPPER DOCK
TRACK NO. 3-2
292.34 W
30'-0"

PHELPS DODGE AT
AJO, ARIZONA

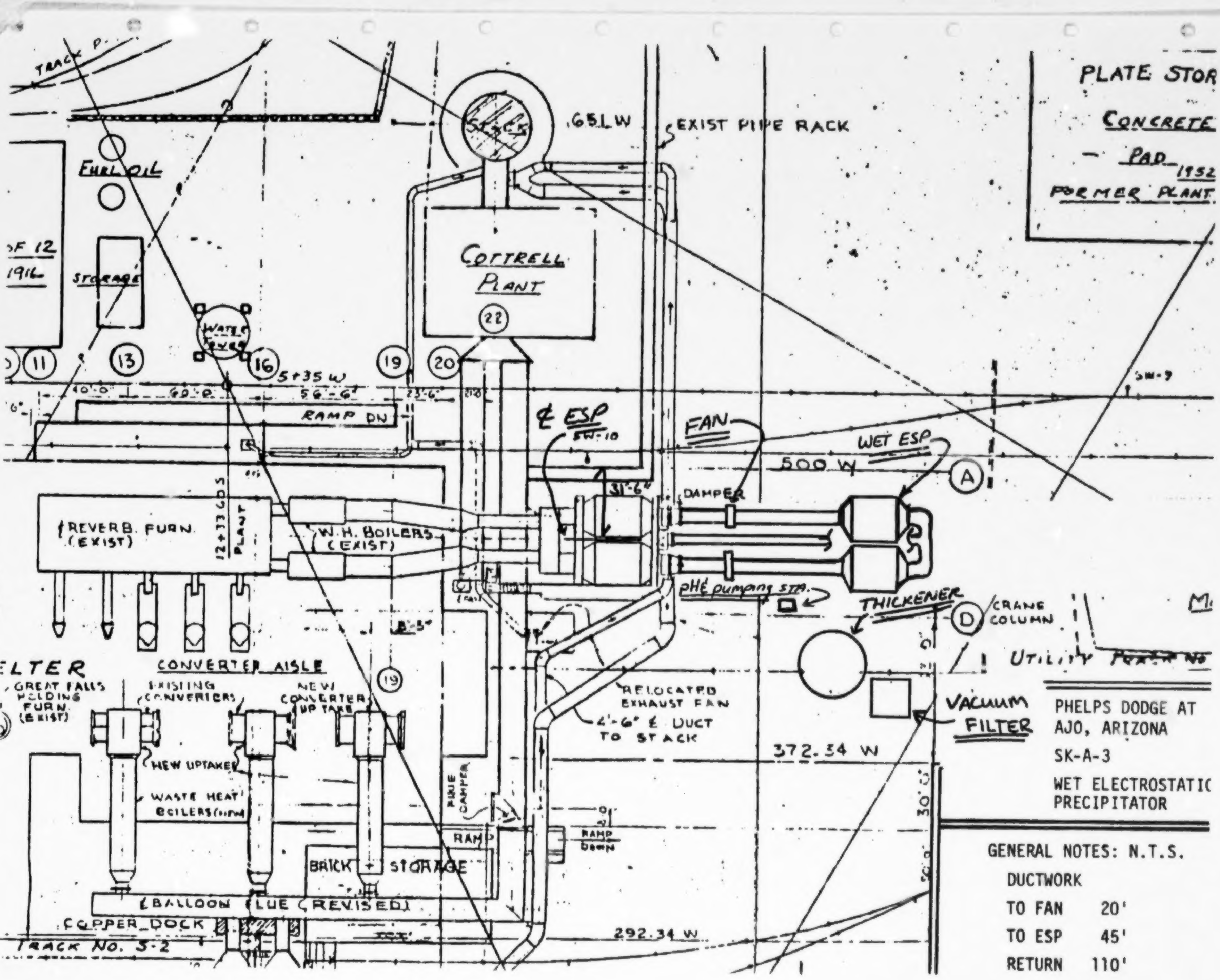
SK-A-2

WET ELECTROSTATIC
PRECIPITATOR

GENERAL NOTES: N.T.S.

DUCTWORK

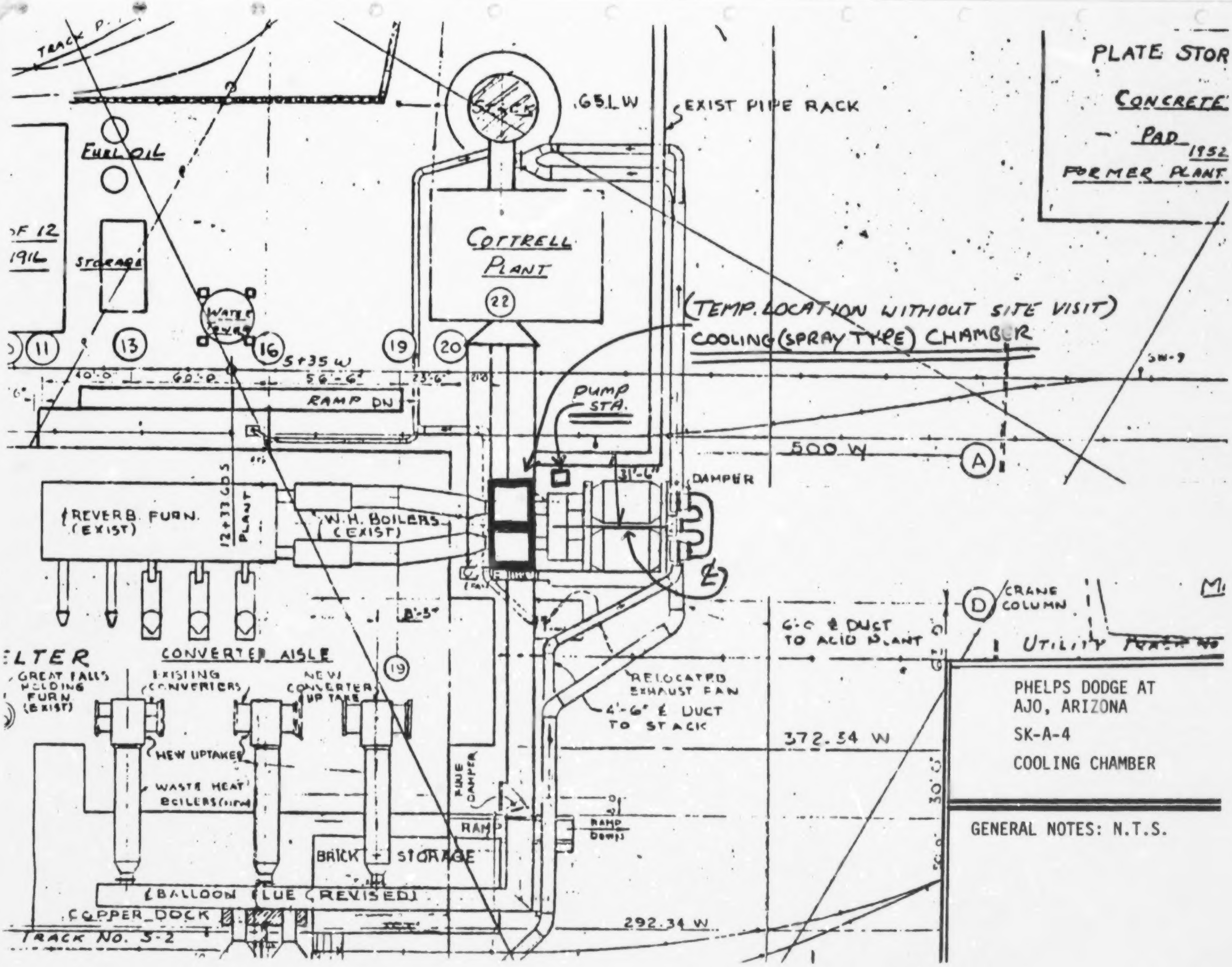
TO FAN	20.0'
TO C.C.	20.0'
TO ESP	45.0'
RETURN	140.0'


TRACK P.
PLATE STOR
CONCRETE
PAD 1952
FORMER PLANT
.651 W
EXIST PIPE RACK
STACK
FUEL OIL
OF 12
1916
STORAGE
COTTRELL PLANT
22
WATER TOWER
11
13
16
19
20
5+35 W
40'-0"
60'-0"
56'-6"
23'-6"
RAMP DN
SW-9
℄ ESP
SW-10
FAN
WET ESP
500 W
A
31'-6"
DAMPER
REVERB. FURN. (EXIST)
12+33 CDS PLANT
W.H. BOILERS (EXIST)
pH pumping STA.
THICKENER
D
CRANE COLUMN
UTILITY
M
ELTER
CONVERTER AISLE
GREAT FALLS HOLDING FURN. (EXIST)
EXISTING CONVERTERS
NEW CONVERTER UP TAKE
19
NEW UPTAKES
WASTE HEAT BOILERS
RELOCATED EXHAUST FAN
4'-6" ℄ DUCT TO STACK
VACUUM FILTER
372.34 W
FLUE DAMPER
RAMP
RAMP DOWN
BRICK STORAGE
℄ BALLOON FLUE (REVISED)
COPPER DOCK
TRACK NO. 5-2
292.34 W
30'-0"

PHELPS DODGE AT
AJO, ARIZONA
SK-A-3
WET ELECTROSTATIC
PRECIPITATOR

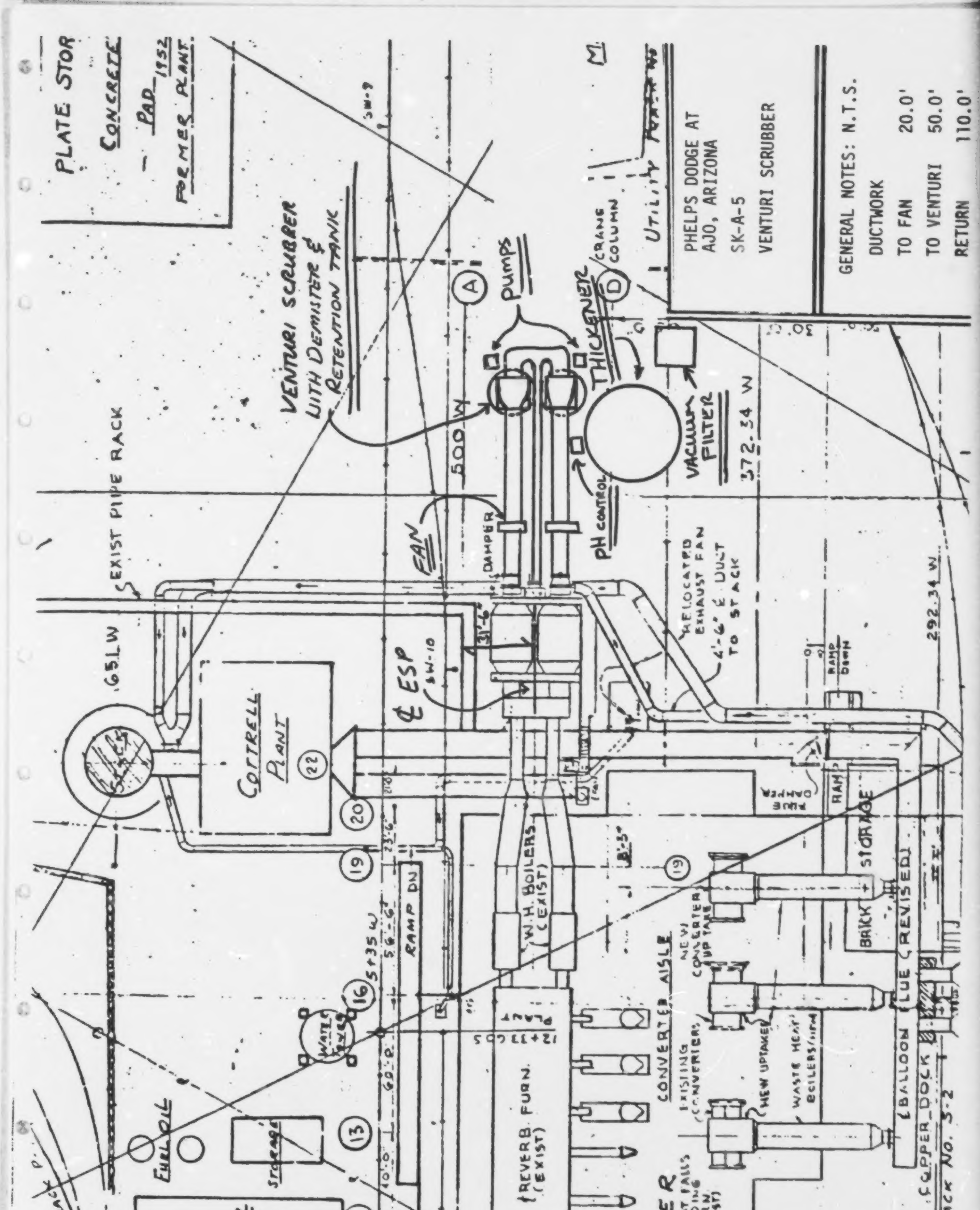
GENERAL NOTES: N.T.S.

DUCTWORK	
TO FAN	20'
TO ESP	45'
RETURN	110'


TRACK
PLATE STOR
CONCRETE
PAD
1952
FORMER PLANT
FUEL OIL
STORAGE
OF 12
1916
STACK
.65 L W
EXIST PIPE RACK
COTTRELL PLANT
22
11
13
WATER TOWER
16
5+35 W
19
20
(TEMP. LOCATION WITHOUT SITE VISIT)
COOLING (SPRAY TYPE) CHAMBER
SW-9
40'-0"
60'-0"
56'-6"
23'-6"
RAMP DN
PUMP STA.
500 W
A
31'-6"
DAMPER
REVERB. FURN. (EXIST)
12+33 CDS
PLANT
W.H. BOILERS (EXIST)
D
CRANE COLUMN
8'-5"
6'-0" ℄ DUCT TO ACID PLANT
UTILITY
ELTER
CONVERTER AISLE
GREAT FALLS HOLDING FURN (EXIST)
EXISTING CONVERTERS
NEW CONVERTER UPTAKE
19
RELOCATED EXHAUST FAN
4'-6" ℄ DUCT TO STACK
NEW UPTAKE
WASTE HEAT BOILERS
FLUE DAMPER
372.34 W
30'-0"
RAMP
RAMP DOWN
BRICK STORAGE
℄ BALLOON FLUE (REVISED)
COPPER DOCK
TRACK No. S-2
292.34 W

PHELPS DODGE AT
AJO, ARIZONA
SK-A-4
COOLING CHAMBER

GENERAL NOTES: N.T.S.


PHELPS DODGE AT
AJO, ARIZONA
SK-A-5
VENTURI SCRUBBER
GENERAL NOTES: N.T.S.
DUCTWORK
TO FAN 20.0'
TO VENTURI 50.0'
RETURN 110.0'
PLATE STOR
CONCRETE PAD 1952
FORMER PLANT
VENTURI SCRUBBER WITH DEMISTER & RETENTION TANK
PUMPS
A
D
CRANE COLUMN
THICKENER
UTILITY
VACUUM FILTER
372.34 W
pH CONTROL
500 W
FAN
DAMPER
EXIST PIPE RACK
651 W
31'-6"
ESP SW-10
RELOCATED EXHAUST FAN
4'-6" E DUCT TO STACK
292.34 W
RAMP DOWN
COTTRELL PLANT
22
STACK
20
19
23'-6"
21'-0"
18'-5"
W.H. BOILERS (EXIST)
FLUE DAMPER
RAMP
STORAGE
BRICK
NEW CONVERTER UPTAKE
BALLOON FLUE (REVISED)
CONVERTER AISLE
EXISTING CONVERTERS
NEW UPTAKE
WASTE HEAT BOILERS (NEW)
COPPER DOCK
TRACK NO. 5-2
REVERB. FURN. (EXIST)
12+33 COS PLANT
RAMP DN
5+35 W
56'-6"
60'-0"
10'-0"
16
13
11
WATER TANKS
FUEL OIL
STORAGE
TRACK
OF 12
1916
LTER
GREAT FALLS HOLDING FURN. (EXIST)
SW-9
30.0'

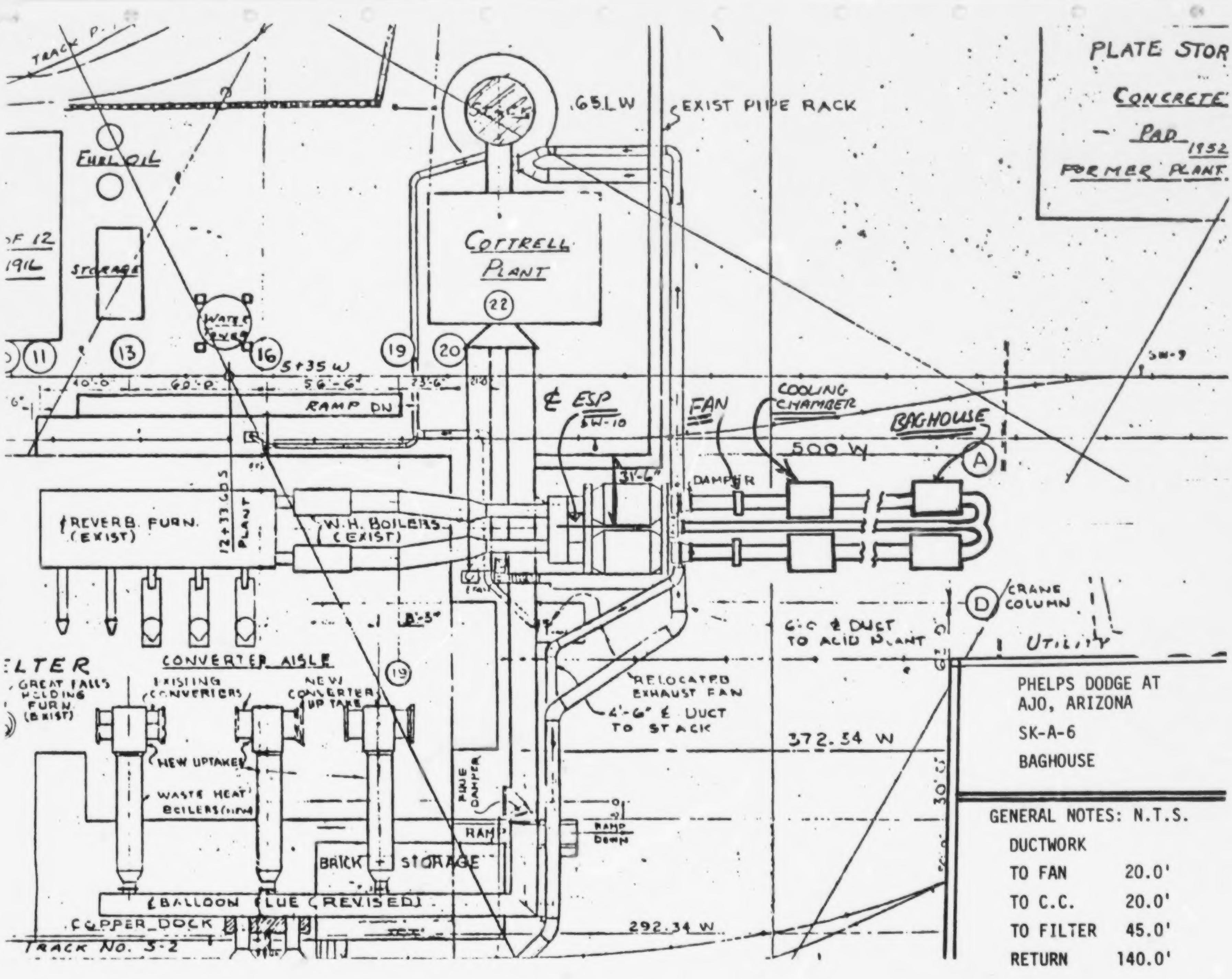


PLATE STOR
CONCRETE
— PAD 1952
FORMER PLANT
TRACK P.
EXIST PIPE RACK
.65 L W
STACK
FUEL OIL
OF 12
1916
STORAGE
COTTRELL PLANT
22
WATER TOWER
11
13
16
19
20
5+35 W
40'-0"
60'-0"
56'-6"
23'-6"
6"
RAMP DN
SW-9
℄ ESP
SW-10
FAN
COOLING CHAMBER
BAGHOUSE
500 W
DAMPER
31'-6"
A
REVERB. FURN. (EXIST)
12+33 COS PLANT
W.H. BOILERS (EXIST)
D
CRANE COLUMN
6'-0 ℄ DUCT TO ACID PLANT
UTILITY
8'-3"
ELTER
CONVERTER AISLE
GREAT FALLS HOLDING FURN. (EXIST)
EXISTING CONVERTERS
NEW CONVERTER UPTAKE
19
RELOCATED EXHAUST FAN
4'-6" ℄ DUCT TO STACK
372.34 W
NEW UPTAKES
WASTE HEAT BOILERS (NEW)
FLUE DAMPER
RAMP
RAMP DOWN
BRICK + STORAGE
(BALLOON FLUE (REVISED)
COPPER DOCK
TRACK NO. S-2
292.34 W
30'-0"

PHELPS DODGE AT
AJO, ARIZONA
SK-A-6
BAGHOUSE

GENERAL NOTES: N.T.S.

DUCTWORK	
TO FAN	20.0'
TO C.C.	20.0'
TO FILTER	45.0'
RETURN	140.0'

APPENDIX D

EPA PROCESS WEIGHT REGULATIONS:
PARTICULATE MATTER FROM STATIONARY PROCESS SOURCES.

Subpart P—Standards of Performance for Primary Copper Smelters [26]

§ 60.160 Applicability and designation of affected facility.

The provisions of this subpart are applicable to the following affected facilities in primary copper smelters: Dryer, roaster, smelting furnace, and copper converter.

§ 60.161 Definitions.

As used in this subpart, all terms not defined herein shall have the meaning given them in the Act and in subpart A of this part.

(a) "Primary copper smelter" means any installation or any intermediate process engaged in the production of copper from copper sulfide ore concentrates through the use of pyrometallurgical techniques.

(b) "Dryer" means any facility in which a copper sulfide ore concentrate charge is heated in the presence of air to eliminate a portion of the moisture from the charge, provided less than 5 percent of the sulfur contained in the charge is eliminated in the facility.

(c) "Roaster" means any facility in which a copper sulfide ore concentrate charge is heated in the presence of air to eliminate a significant portion (5 percent or more) of the sulfur contained in the charge.

(d) "Calcine" means the solid materials produced by a roaster.

(e) "Smelting" means processing techniques for the melting of a copper sulfide ore concentrate or calcine charge leading to the formation of separate layers of molten slag, molten copper, and/or copper matte.

(f) "Smelting furnace" means any vessel in which the smelting of copper sulfide ore concentrates or calcines is performed and in which the heat necessary for smelting is provided by an electric current, rapid oxidation of a portion of the sulfur contained in the concentrate as it passes through an oxidizing atmosphere, or the combustion of a fossil fuel.

(g) "Copper converter" means any vessel to which copper matte is charged and oxidized to copper.

(h) "Sulfuric acid plant" means any facility producing sulfuric acid by the contact process.

(i) "Fossil fuel" means natural gas, petroleum, coal, and any form of solid, liquid, or gaseous fuel derived from such materials for the purpose of creating useful heat.

(j) "Reverberatory smelting furnace" means any vessel in which the smelting of copper sulfide ore concentrates or calcines is performed and in which the heat necessary for smelting is provided primarily by combustion of a fossil fuel.

(k) "Total smelter charge" means the weight (dry basis) of all copper sulfides ore concentrates processed at a primary copper smelter, plus the weight of all other solid materials introduced into the roasters and smelting furnaces at a primary copper smelter, except calcine, over a one-month period.

(l) "High level of volatile impurities" means a total smelter charge containing more than 0.2 weight percent arsenic, 0.1 weight percent antimony, 4.5 weight percent lead or 5.5 weight percent zinc, on a dry basis.

§ 60.162 Standard for particulate matter.

(a) On and after the date on which the performance test required to be conducted by § 60.8 is completed, no owner or operator subject to the provisions of this subpart shall cause to be discharged into the atmosphere from any dryer any gases which contain particulate matter in excess of 50 mg/dscm (0.022 gr/dscf).

§ 60.163 Standard for sulfur dioxide.

(b) On and after the date on which the performance test required to be conducted by § 60.8 is completed, no owner or operator subject to the provisions of this subpart shall cause to be discharged into the atmosphere from any roaster, smelting furnace, or copper converter any gases which contain sulfur dioxide in excess of 0.065 percent by volume, except as provided in paragraphs (b) and (c) of this section.

(b) Reverberatory smelting furnaces shall be exempted from paragraph (a) of this section during periods when the total smelter charge at the primary copper smelter contains a high level of volatile impurities.

(c) A change in the fuel combusted in a reverberatory furnace shall not be considered a modification under this part.

§ 60.164 Standard for visible emissions.

(a) On and after the date on which the performance test required to be conducted by § 60.8 is completed, no owner or operator subject to the provisions of this subpart shall cause to be discharged into the atmosphere from any dryer any visible emissions which exhibit greater than 20 percent opacity.

(b) On and after the date on which the performance test required to be conducted by § 60.8 is completed, no owner or operator subject to the provisions of this subpart shall cause to be discharged into the atmosphere from any affected facility that uses a sulfuric acid to comply with the standard set forth in § 60.163, any visible emissions which exhibit greater than 20 percent opacity.

§ 60.165 Monitoring of operations.

(a) The owner or operator of any primary copper smelter subject to § 60.163 (b) shall keep a monthly record of the total smelter charge and the weight percent (dry basis) of arsenic, antimony, lead and zinc contained in this charge. The analytical methods and procedures employed to determine the weight of the total smelter charge and the weight percent of arsenic, antimony, lead and zinc shall be approved by the Administrator and shall be accurate to within plus or minus ten percent. [30]

(b) The owner or operator of any primary copper smelter subject to the provisions of this subpart shall install and operate:

(1) A continuous monitoring system to monitor and record the opacity of gases discharged into the atmosphere from any dryer. The span of this system shall be set at 80 to 100 percent opacity.

(2) A continuous monitoring system to monitor and record sulfur dioxide emissions discharged into the atmosphere from any roaster, smelting furnace or copper converter subject to § 60.163 (a). The span of this system shall be set at a sulfur dioxide concentration of 0.20 percent by volume.

(i) The continuous monitoring system performance evaluation required under § 60.13(c) shall be completed prior to the initial performance test required under § 60.8. During the performance evaluation, the span of the continuous monitoring system may be set at a sulfur dioxide concentration of 0.15 percent by volume if necessary to maintain the system output between 20 percent and 90 percent of full scale. Upon completion of the continuous monitoring system performance evaluation, the span of the continuous monitoring system shall be set at a sulfur dioxide concentration of 0.20 percent by volume.

(ii) For the purpose of the continuous monitoring system performance evaluation required under § 60.13(c) the reference method referred to under the Field Test for Accuracy (Relative) in Performance Specification 2 of Appendix B to this part shall be Reference Method 6. For the performance evaluation, each concentration measurement shall be of one hour duration. The pollutant gas used to prepare the calibration gas mixtures required under paragraph 2.1, Performance Specification 2 of Appendix B, and for calibration checks under § 60.13 (d), shall be sulfur dioxide.

(c) Six-hour average sulfur dioxide concentrations shall be calculated and recorded daily for the four consecutive 6-hour periods of each operating day. Each six-hour average shall be determined as the arithmetic mean of the appropriate six contiguous one-hour average sulfur dioxide concentrations provided by the continuous monitoring system installed under paragraph (b) of this section.

(d) For the purpose of reports required under § 60.7(c), periods of excess emissions that shall be reported are defined as follows:

(1) Opacity. Any six-minute period during which the average opacity, as measured by the continuous monitoring system installed under paragraph (b) of this section, exceeds the standard under § 60.164(a).

(2) Sulfur dioxide. Any six-hour period, as described in paragraph (c) of this section, during which the average emissions of sulfur dioxide, as measured by the continuous monitoring system installed under paragraph (b) of this section, exceeds the standard under § 60.163.

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§ 60.166 Test methods and procedures.

(a) The reference methods in Appendix A to this part, except as provided for in § 60.8(b), shall be used to determine compliance with the standards prescribed in §§ 60.162, 60.163 and 60.164 as follows:

(1) Method 5 for the concentration of particulate matter and the associated moisture content.

(2) Sulfur dioxide concentrations shall be determined using the continuous monitoring system installed in accordance with § 60.165(b). One 6-hour average period shall constitute one run. The monitoring system drift during any run shall not exceed 2 percent of span.

(b) For Method 5, Method 1 shall be used for selecting the sampling site and the number of traverse points, Method 2 for determining velocity and volumetric flow rate and Method 3 for determining the gas analysis. The sampling time for each run shall be at least 60 minutes and the minimum sampling volume shall be 0.85 dscm (30 dscf) except that smaller times or volumes, when necessitated by process variables or other factors, may be approved by the Administrator.

§ 52.126 Control strategy and regulations: Particulate matter.

(a) The requirements of §§ 51.13 and 51.22 of this chapter are not met since the plan does not provide the degree of control necessary to attain and maintain the national standards for particulate matter in the Phoenix-Tucson Intrastate Region. Therefore, Regulation 7-1-3.6 (process industries) of the Arizona Rules and Regulations for Air Pollution Control, Rule 31(E) (process industries) in Regulation III of the Maricopa County Air Pollution Control Rules and Regulations, and Rule 2(B) (process industries) in Regulation II of the Rules and Regulations of the Pima County Air Pollution Control District are disapproved for the Phoenix-Tucson Intrastate Region.

(b) *Replacement regulation for Regulation 7-1-3.6 of the Arizona Rules and Regulations for Air Pollution Control, Rule 31(E) of Regulation III of the Maricopa County Air Pollution Control Rules and Regulations, and Rule 2(B) of Regulation II of the Rules and Regulations of Pima County Air Pollution Control District (Phoenix-Tucson Intrastate Region)*.—(1) No owner or operator of any stationary process source in the Phoenix-Tucson Intrastate Region (§ 81.36 of this chapter) shall discharge or cause the discharge of particulate matter into the atmosphere in excess of the hourly rate shown in the following table for the process weight rate identified for such source:

Process weight rate (pounds per hour)	Emission rate (pounds per hour)	Process weight rate (pounds per hour)	Emission rate (pounds per hour)
50	0.36	60,000	29.60
100	0.55	80,000	31.19
500	1.53	120,000	33.28
1,000	2.25	160,000	34.85
5,000	6.34	200,000	36.11
10,000	9.73	400,000	40.35
20,000	14.99	1,000,000	46.72

(i) Interpolation of the data in the table for process weight rates up to 60,000 lbs/hr shall be accomplished by use of the equation:

$$E=3.59\,P^{0.62}\quad P\leq 30\text{ tons/h}$$

and interpolation and extrapolation of the data for process weight rates in excess of 60,000 lbs/hr shall be accomplished by use of the equation:

$$E=17.31\,P^{0.16}\quad P>30\text{ tons/h}$$

Where: E = Emissions in pounds per hour
P = Process weight in tons per hour

(ii) Process weight is the total weight of all materials and solid fuels introduced into any specific process. Liquid and gaseous fuels and combustion air will not be considered as part of the process weight. For a cyclical or batch operation, the process weight per hour will be derived by dividing the total process weight by the number of hours in one complete operation from the beginning of the given process to the completion thereof, excluding any time during which the equipment is idle. For a continuous operation, the process weight per hour will be derived by dividing the process weight for a given period of time by the number of hours in that period.

(iii) For purposes of this regulation, the total process weight from all similar units employing a similar type process shall be used in determining the maximum allowable emission of particulate matter.

(2) Paragraph (b)(1) of this section shall not apply to incinerators, fuel burning installations, or Portland cement plants having a process weight rate in excess of 250,000 lb/h.

(3) No owner or operator of a Portland cement plant in the Phoenix-Tucson Intrastate Region (§ 81.36 of this chapter) with a process weight rate in excess of 250,000 lb/h shall discharge or cause the discharge of particulate matter into the atmosphere in excess of the amount specified in § 60.62 of this chapter.

(5) The test methods and procedures used to determine compliance with this paragraph are set forth below. The methods referenced are contained in the appendix to part 60 of this chapter. Equivalent methods and procedures may be used if approved by the Administrator.

(i) For each sampling repetition, the average concentration of particulate matter shall be determined by using method 5. Traversing during sampling by method 5 shall be according to method 1. The minimum sampling time shall be 2 hours and the minimum sampling volume shall be 60 ft^3 (1.70 m^3), corrected to standard conditions on a dry basis.

(ii) The volumetric flow rate of the total effluent shall be determined by using method 2 and traversing according to method 1. Gas analysis shall be performed using the integrated sample technique of method 3, and moisture content shall be determined by the condenser technique of method 4.

(iii) All tests shall be conducted while the source is operating at the maximum production or combustion rate at which such source will be operated. During the tests, the source shall burn fuels or combinations of fuels, use raw materials, and maintain process conditions representative of normal operation, and shall operate under such other relevant conditions as the Administrator shall specify.

(c) *Replacement regulation for Regulation 7-1-4(c) (Fossil fuel-fired steam generators in the Four Corners Interstate Region)*. (1) This paragraph is applicable to the fossil fuel-fired steam generating equipment designated as Units 1, 2, and 3 at the Navajo Power Plant in the Arizona portion of the Four Corners Interstate Region (§ 81.121 of this chapter).

(2) No owner or operator of the fossil fuel-fired steam generating equipment to which this paragraph is applicable shall discharge or cause the discharge of sulfur oxides into the atmosphere in excess of the amount prescribed by the following equations:

$$E=\frac{5.7\times 10^{3}S}{H}\text{ or }e=\frac{5.7\times 10^{3}S}{h}$$

where: E = Allowable sulfur oxides emissions (lb./10^6 B.t.u.).
e = Allowable sulfur oxides emissions (gm./10^6 gm.-cal.).
S = Sulfur content, in percent by weight, of fuel being burned.
H = Heat content of fuel (B.t.u./lb.).
h = Heat content of fuel (gm.-cal./gm.).

(3) For the purposes of this paragraph:

(i) E shall not exceed 0.90 lb. SO_2/10^6 B.t.u. (1.6 gm. SO_2/10^6 gm.-cal.).

(ii) If emissions are less than 0.16 lb. SO_2/10^6 B.t.u. (0.29 gm. SO_2/10^6 gm.-cal.), the requirements of paragraph (c)(2) of this section shall not apply.

(4) Compliance with this paragraph shall be in accordance with the provisions of § 52.134(a).

(5) The test methods and procedures used to determine compliance with this paragraph shall be those prescribed in § 60.46 (c), (d), and (e) of this chapter.

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EPA TEST METHODS 1 THROUGH 8 PROCEDURES

federal register

THURSDAY, AUGUST 18, 1977
PART II

THE NATIONAL ARCHIVES OF THE UNITED STATES • 1934 •

ENVIRONMENTAL PROTECTION AGENCY

■

STANDARDS OF PERFORMANCE FOR NEW STATIONARY SOURCES

Revision to Reference Method 1-8

Title 40—Protection of Environment

CHAPTER I—ENVIRONMENTAL PROTECTION AGENCY

[FRL 754-8]

PART 60—STANDARDS OF PERFORMANCE FOR NEW STATIONARY SOURCES

Revision to Reference Methods 1-8

AGENCY: Environmental Protection Agency.

ACTION: Final Rule.

SUMMARY: This rule revises Reference Methods 1 through 8, the detailed requirements used to measure emissions from affected facilities to determine whether they are in compliance with a standard of performance. The methods were originally promulgated December 23, 1971, and since that time several revisions became apparent which would clarify, correct and improve the methods. These revisions make the methods easier to use, and improve their accuracy and reliability.

EFFECTIVE DATE: September 19, 1977.

ADDRESSES: Copies of the comment letters are available for public inspection and copying at the U.S. Environmental Protection Agency, Public Information Reference Unit (EPA Library), Room 2922, 401 M Street, S.W., Washington, D.C. 20460. A summary of the comments and EPA's responses may be obtained upon written request from the EPA Public Information Center (PM-215), 401 M Street, S.W., Washington, D.C. 20460 (specify "Public Comment Summary: Revisions to Reference Methods 1-8 in Appendix A of Standards of Performance for New Stationary Sources").

FOR FURTHER INFORMATION CONTACT:

Don R. Goodwin, Emission Standards and Engineering Division, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, telephone No. 919-541-5271.

SUPPLEMENTARY INFORMATION: The amendments were proposed on June 8, 1976 (40 FR 23060). A total of 55 comment letters were received during the comment period—34 from industry, 15 from governmental agencies, and 6 from other interested parties. They contained numerous suggestions which were incorporated in the final revisions.

Changes common to all eight of the reference methods are: (1) the clarification of procedures and equipment specifications resulting from the comments, (2) the addition of guidelines for alternative procedures and equipment to make prior approval of the Administrator unnecessary and (3) the addition of an introduction to each reference method discussing the general use of the method and delineating the procedure for using alternative methods and equipment.

Specific changes to the methods are:

METHOD 1

1. The provision for the use of more than two traverse diameters, when specified by the Administrator, has been deleted. If one traverse diameter is in a plane containing the greatest expected concentration variation, the intended purpose of the deleted paragraph will be fulfilled.

2. Based on recent data from Fluidyne (Particulate Sampling Strategies for Large Power Plants Including Nonuniform Flow, EPA-600/2-76-170, June 1976) and Entropy Environmentalists (Determination of the Optimum Number of Traverse Points: An Analysis of Method 1 Criteria (draft), Contract No. 68-01-3172); the number of traverse points for velocity measurements has been reduced and the 2:1 length to width ratio requirement for cross-sectional layout of rectangular ducts has been replaced by a "balanced matrix" scheme.

3. Guidelines for sampling in stacks containing cyclonic flow and stacks smaller than about 0.31 meter in diameter or 0.071 m² in cross-sectional area will be published at a later date.

4. Clarification has been made as to when a check for cyclonic flow is necessary; also, the suggested procedure for determination of unacceptable flow conditions has been revised.

METHOD 2

1. The calibration of certain pitot tubes has been made optional. Appropriate construction and application guidelines have been included.

2. A detailed calibration procedure for temperature gauges has been included.

3. A leak check procedure for pitot lines has been included.

METHOD 3

1. The applicability of the method has been confined to fossil-fuel combustion processes and to other processes where it has been determined that components other than O_2, CO_2, CO, and N_2 are not present in concentrations sufficient to affect the final results.

2. Based on recent research information (Particulate Sampling Strategies for Large Power Plants Including Nonuniform Flow, EPA-600/2-76-170, June 1976), the requirement for proportional sampling has been dropped and replaced with the requirement for constant rate sampling. Proportional and constant rate sampling have been found to give essentially the same result.

3. The "three consecutive" requirement has been replaced by "any three" for the determination of molecular weight, CO_2 and O_2.

4. The equation for excess air has been revised to account for the presence of CO.

5. A clearer distinction has been made between molecular weight determination and emission rate correction factor determination.

6. Single point, integrated sampling has been included.

METHOD 4

1. The sampling time of 1 hour has been changed to a total sampling time which will span the length of time the pollutant emission rate is being determined or such time as specified in an applicable subpart of the standards.

2. The requirement for proportional sampling has been dropped and replaced with the requirement for constant rate sampling.

3. The leak check before the test run has been made optional; the leak check after the run remains mandatory.

METHOD 5

1. The following alternatives have been included in the method:

a. The use of metal probe liners.

b. The use of other materials of construction for filter holders and probe liner parts.

c. The use of polyethylene wash bottles and sample storage containers.

d. The use of desiccants other than silica gel or calcium sulfate, when appropriate.

e. The use of stopcock grease other than silicone grease, when appropriate.

f. The drying of filters and probe-filter catches at elevated temperatures, when appropriate.

g. The combining of the filter and probe washes into one container.

2. The leak check prior to a test run has been made optional. The post-test leak check remains mandatory. A method for correcting sample volume for excessive leakage rates has been included.

3. Detailed leak check and calibration procedures for the metering system have been included.

METHOD 6

1. Possible interfering agents of the method have been delineated.

2. The options of: (a) using a Method 8 impinger system, or (b) determining SO_2 simultaneously with particulate matter, have been included in the method.

3. Based on recent research data, the requirement for proportional sampling has been dropped and replaced with the requirement for constant rate sampling.

4. Tests have shown that isopropanol obtained from commercial sources occasionally has peroxide impurities that will cause erroneously low SO_2 measurements. Therefore, a test for detecting peroxides in isopropanol has been included in the method.

5. The leak check before the test run has been made optional; the leak check after the run remains mandatory.

6. A detailed calibration procedure for the metering system has been included in the method.

METHOD 7

1. For variable wave length spectrophotometers, a scanning procedure for determining the point of maximum absorbance has been incorporated as an option.

METHOD 8

1. Known interfering compounds have been listed to avoid misapplication of the method.

2. The determination of filterable particulate matter (including acid mist) simultaneously with SO_2 and SO_3 has been allowed where applicable.

3. Since occasionally some commercially available quantities of isopropanol

have peroxide impurities that will cause erroneously high sulfuric acid mist measurements, a test for peroxides in isopropanol has been included in the method.

4. The gravimetric technique for moisture content (rather than volumetric) has been specified because a mixture of isopropyl alcohol and water will have a volume less than the sum of the volumes of its content.

5. A closer correspondence has been made between similar parts of Methods 8 and 5.

MISCELLANEOUS

Several commenters questioned the meaning of the term "subject to the approval of the Administrator" in relation to using alternate test methods and procedures. As defined in § 60.2 of subpart A, the "Administrator" includes any authorized representative of the Administrator of the Environmental Protection Agency. Authorized representatives are EPA officials in EPA Regional Offices or State, local, and regional governmental officials who have been delegated the responsibility of enforcing regulations under 40 CFR 60. These officials in consultation with other staff members familiar with technical aspects of source testing will render decisions regarding acceptable alternate test procedures.

In accordance with section 117 of the Act, publication of these methods was preceded by consultation with appropriate advisory committees, independent experts, and Federal departments, and agencies.

(Secs. 111, 114 and 301(a) of the Clean Air Act, sec. 4(a) of Pub. L. No. 91–604, 84 Stat. 1683; sec. 4(a) of Pub. L. No. 91–604, 84 Stat. 1687; sec. 2 of Pub. L. No. 90–148, 81 Stat. 504 [42 U.S.C. 1857c–6, 1857c–9, 1857g(a)].)

NOTE.—The Environmental Protection Agency has determined that this document does not contain a major proposal requiring preparation of an Economic Impact Analysis under Executive Orders 11821 and 11949 and OMB Circular A–107.

Dated: August 10, 1977.

DOUGLAS M. COSTLE,
Administrator.

Part 60 of Chapter I of Title 40 of the Code of Federal Regulations is amended by revising Methods 1 through 8 of Appendix A—Reference Methods as follows:

APPENDIX A—REFERENCE METHODS

The reference methods in this appendix are referred to in § 60.8 (Performance Tests) and § 60.11 (Compliance With Standards and Maintenance Requirements) of 40 CFR Part 60, Subpart A (General Provisions). Specific uses of these reference methods are described in the standards of performance contained in the subparts, beginning with Subpart D.

Within each standard of performance, a section titled "Test Methods and Procedures" is provided to (1) identify the test methods applicable to the facility subject to the respective standard and (2) identify any special instructions or conditions to be followed when applying a method to the respective facility. Such instructions (for example, establish sampling rates, volumes, or temperatures) are to be used either in addition to, or as a substitute for procedures in a reference method. Similarly, for sources subject to emission monitoring requirements, specific instructions pertaining to any use of a reference method are provided in the subpart or in Appendix B.

Inclusion of methods in this appendix is not intended as an endorsement or denial of their applicability to sources that are not subject to standards of performance. The methods are potentially applicable to other sources; however, applicability should be confirmed by careful and appropriate evaluation of the conditions prevalent at such sources.

The approach followed in the formulation of the reference methods involves specifications for equipment, procedures, and performance. In concept, a performance specification approach would be preferable in all methods because this allows the greatest flexibility to the user. In practice, however, this approach is impractical in most cases because performance specifications cannot be established. Most of the methods described herein, therefore, involve specific equipment specifications and procedures, and only a few methods in this appendix rely on performance criteria.

Minor changes in the reference methods should not necessarily affect the validity of the results and it is recognized that alternative and equivalent methods exist. Section 60.8 provides authority for the Administrator to specify or approve (1) equivalent methods, (2) alternative methods, and (3) minor changes in the methodology of the reference methods. It should be clearly understood that unless otherwise identified all such methods and changes must have prior approval of the Administrator. An owner employing such methods or deviations from the reference methods without obtaining prior approval does so at the risk of subsequent disapproval and retesting with approved methods.

Within the reference methods, certain specific equipment or procedures are recognized as being acceptable or potentially acceptable and are specifically identified in the methods. The items identified as acceptable options may be used without approval but must be identified in the test report. The potentially approvable options are cited as "subject to the approval of the Administrator" or as "or equivalent." Such potentially approvable techniques or alternatives may be used at the discretion of the owner without prior approval. However, detailed descriptions for applying these potentially approvable techniques or alternatives are not provided in the reference methods. Also, the potentially approvable options are not necessarily acceptable in all applications. Therefore, an owner electing to use such potentially approvable techniques or alternatives is responsible for: (1) assuring that the techniques or alternatives are in fact applicable and are properly executed; (2) including a written description of the alternative method in the test report (the written method must be clear and must be capable of being performed without additional instruction, and the degree of detail should be similar to the detail contained in the reference methods); and (3) providing any rationale or supporting data necessary to show the validity of the alternative in the particular application. Failure to meet these requirements can result in the Administrator's disapproval of the alternative.

METHOD 1—SAMPLE AND VELOCITY TRAVERSES FOR STATIONARY SOURCES

1. *Principle and Applicability*

1.1 Principle. To aid in the representative measurement of pollutant emissions and/or total volumetric flow rate from a stationary source, a measurement site where the effluent stream is flowing in a known direction is selected, and the cross-section of the stack is divided into a number of equal areas. A traverse point is then located within each of these equal areas.

1.2 Applicability. This method is applicable to flowing gas streams in ducts, stacks, and flues. The method cannot be used when: (1) flow is cyclonic or swirling (see Section 2.4), (2) a stack is smaller than about 0.30 meter (12 in.) in diameter, or 0.071 m² (113 in.²) in cross-sectional area, or (3) the measurement site is less than two stack or duct diameters downstream or less than a half diameter upstream from a flow disturbance.

The requirements of this method must be considered before construction of a new facility from which emissions will be measured; failure to do so may require subsequent alterations to the stack or deviation from the standard procedure. Cases involving variants are subject to approval by the Administrator, U.S. Environmental Protection Agency.

2. *Procedure*

2.1 Selection of Measurement Site. Sampling or velocity measurement is performed at a site located at least eight stack or duct diameters downstream and two diameters upstream from any flow disturbance such as a bend, expansion, or contraction in the stack, or from a visible flame. If necessary, an alternative location may be selected, at a position at least two stack or duct diameters downstream and a half diameter upstream from any flow disturbance. For a rectangular cross section, an equivalent diameter (D_e) shall be calculated from the following equation, to determine the upstream and downstream distances.

$$D_e = \frac{2LW}{L+W}$$

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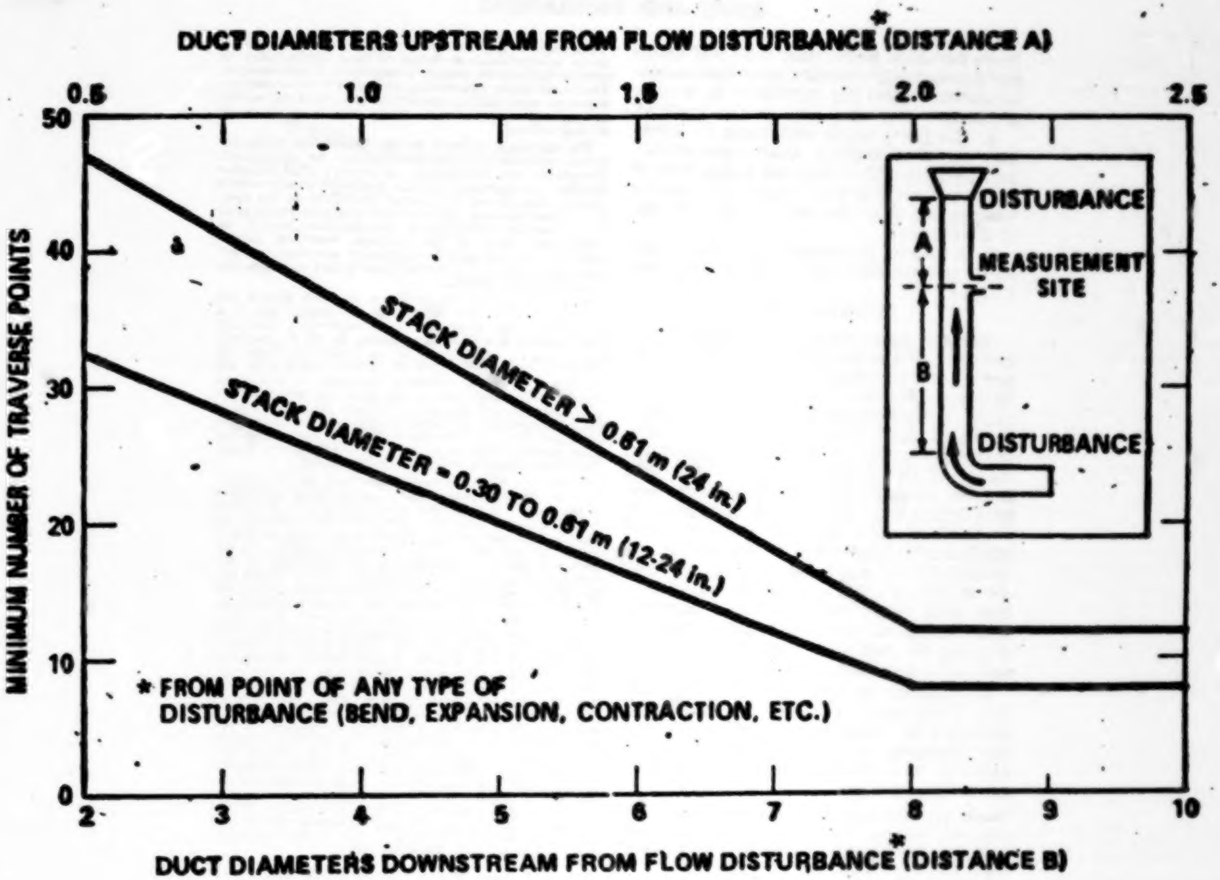

Figure 1-1. Minimum number of traverse points for particulate traverses.

where *L*=length and *W*=width.

2.2 Determining the Number of Traverse Points.

2.2.1 Particulate Traverses. When the eight- and two-diameter criterion can be met, the minimum number of traverse points shall be: (1) twelve, for circular or rectangular stacks with diameters (or equivalent diameters) greater than 0.61 meter (24 in.); (2) eight, for circular stacks with diameters between 0.30 and 0.61 meter (12-24 in.); (3) nine, for rectangular stacks with equivalent diameters between 0.30 and 0.61 meter (12-24 in.).

When the eight- and two-diameter criterion cannot be met, the minimum number of traverse points is determined from Figure 1-1. Before referring to the figure, however, determine the distances from the chosen measurement site to the nearest upstream and downstream disturbances, and divide each distance by the stack diameter or equivalent diameter, to determine the distance in terms of the number of duct diameters. Then, determine from Figure 1-1 the minimum number of traverse points that corresponds: (1) to the number of duct diameters upstream; and (2) to the number of diameters downstream. Select the higher of the two minimum numbers of traverse points, or a greater value, so that for circular stacks the number is a multiple of 4, and for rectangular stacks, the number is one of those shown in Table 1-1.

TABLE 1-1. *Cross-sectional layout for rectangular stacks*

Number of traverse points	Matrix layout
9	3×3
12	4×3
16	4×4
20	5×4
25	5×5
30	6×5
36	6×6
42	7×6
49	7×7

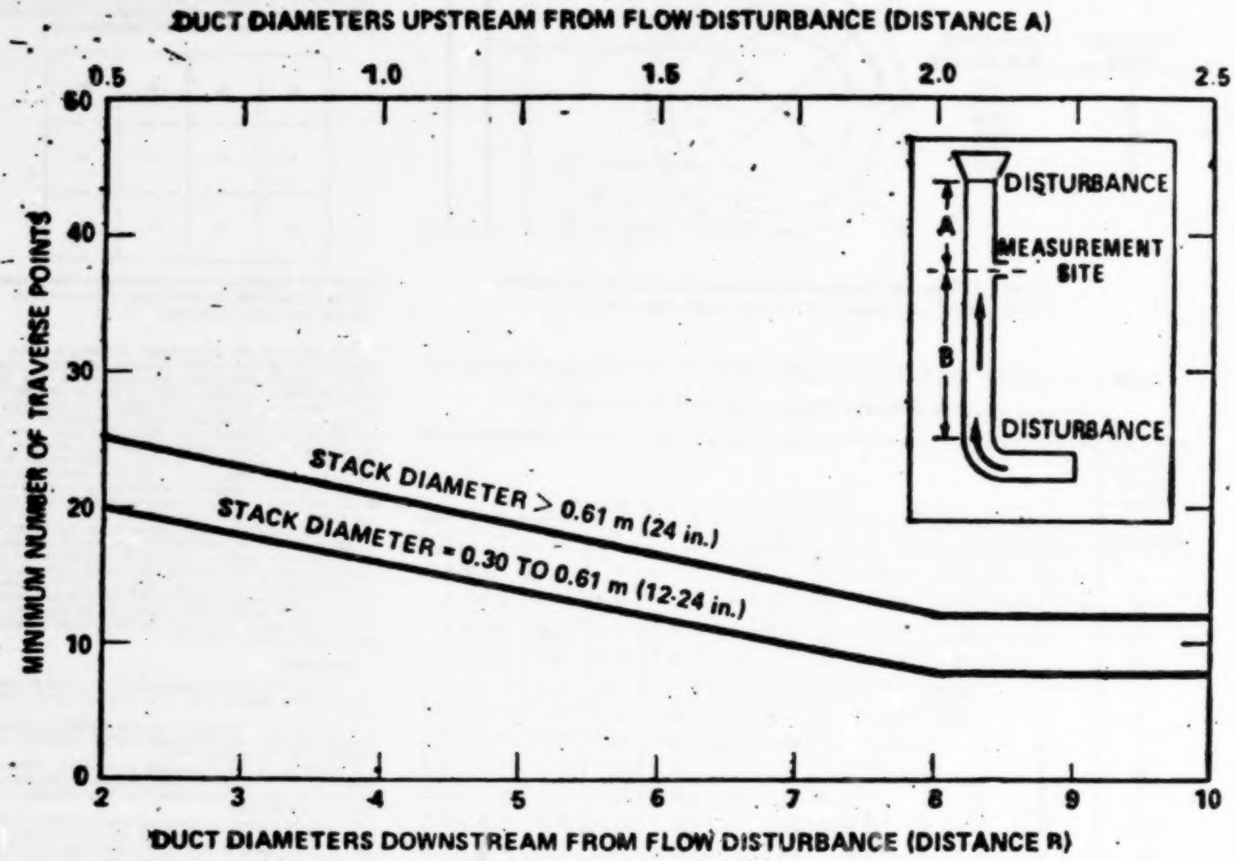

Figure 1-2. Minimum number of traverse points for velocity (nonparticulate) traverses.

2.2.2 Velocity (Non-Particulate) Traverses. When velocity or volumetric flow rate is to be determined (but not particulate matter), the same procedure as that for particulate traverses (Section 2.2.1) is followed, except that Figure 1-2 may be used instead of Figure 1-1.

2.3 Cross-Sectional Layout and Location of Traverse Points.

2.3.1 Circular Stacks. Locate the traverse points on two perpendicular diameters according to Table 1-2 and the example shown in Figure 1-3. Any equation (for examples, see Citations 2 and 3 in the Bibliography) that gives the same values as those in Table 1-2 may be used in lieu of Table 1-2.

For particulate traverses, one of the diameters must be in a plane containing the greatest expected concentration variation, e.g., after bends, one diameter shall be in the plane of the bend. This requirement becomes less critical as the distance from the disturbance increases; therefore, other diameter locations may be used, subject to approval of the Administrator.

In addition, for stacks having diameters greater than 0.61 m (24 in.) no traverse points shall be located within 2.5 centimeters (1.00 in.) of the stack walls; and for stack diameters equal to or less than 0.61 m (24 in.), no traverse points shall be located within 1.3 cm (0.50 in.) of the stack walls. To meet these criteria, observe the procedures given below.

2.3.1.1 Stacks With Diameters Greater Than 0.61 m (24 in.). When any of the traverse points as located in Section 2.3.1 fall within 2.5 cm (1.00 in.) of the stack walls, relocate them away from the stack walls to: (1) a distance of 2.5 cm (1.00 in.); or (2) a distance equal to the nozzle inside diameter, whichever is larger. These relocated traverse points (on each end of a diameter) shall be the "adjusted" traverse points.

Whenever two successive traverse points are combined to form a single adjusted traverse point, treat the adjusted point as two separate traverse points, both in the sampling (or velocity measurement) procedure, and in recording the data.

TRAVERSE POINT	DISTANCE % of diameter
1	4.4
2	14.7
3	29.5
4	70.5
5	85.3
6	95.6

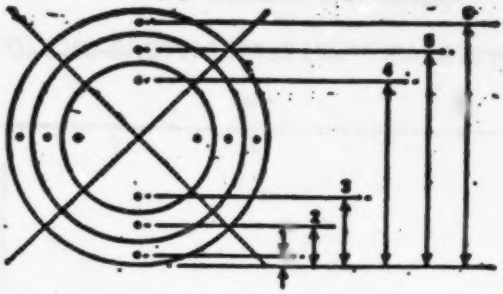

Figure 1-3. Example showing circular stack cross section divided into 12 equal areas, with location of traverse points indicated.

Table 1-2. LOCATION OF TRAVERSE POINTS IN CIRCULAR STACKS
(Percent of stack diameter from inside wall to traverse point)

Traverse point number on a diameter	Number of traverse points on a diameter											
	2	4	6	8	10	12	14	16	18	20	22	24
1	14.6	6.7	4.4	3.2	2.6	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	85.4	25.0	14.6	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3		75.0	29.6	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4		93.3	70.4	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5			85.4	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6			95.6	80.6	65.8	35.6	26.9	22.0	18.8	16.5	14.6	13.2
7				89.5	77.4	64.4	36.6	28.3	23.6	20.4	18.0	16.1
8				96.8	85.4	75.0	63.4	37.5	29.6	25.0	21.8	19.4
9					91.8	82.3	73.1	62.5	38.2	30.6	26.2	23.0
10					97.4	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11						93.3	85.4	78.0	70.4	61.2	39.3	32.3
12						97.9	90.1	83.1	76.4	69.4	60.7	39.8
13							94.3	87.5	81.2	75.0	68.5	60.2
14							98.2	91.5	85.4	79.6	73.8	67.7
15								95.1	89.1	83.5	78.2	72.8
16								98.4	92.5	87.1	82.0	77.0
17									95.6	90.3	85.4	80.6
18									98.6	93.3	88.4	83.9
19										96.1	91.3	86.8
20										98.7	94.0	89.5
21											96.5	92.1
22											98.9	94.5
23												96.8
24												98.9

2.3.1.2 Stacks With Diameters Equal to or Less Than 0.61 m (24 in.). Follow the procedure in Section 2.3.1.1, noting only that any "adjusted" points should be relocated away from the stack walls to: (1) a distance of 1.3 cm (0.50 in.); or (2) a distance equal to the nozzle inside diameter, whichever is larger.

2.3.2 Rectangular Stacks. Determine the number of traverse points as explained in Sections 2.1 and 2.2 of this method. From Table 1-1, determine the grid configuration. Divide the stack cross-section into as many equal rectangular elemental areas as traverse points, and then locate a traverse point at the centroid of each equal area according to the example in Figure 1-4.

The situation of traverse points being too close to the stack walls is not expected to arise with rectangular stacks. If this problem should ever arise, the Administrator must be contacted for resolution of the matter.

2.4 Verification of Absence of Cyclonic Flow. In most stationary sources, the direction of stack gas flow is essentially parallel to the stack walls. However, cyclonic flow may exist (1) after such devices as cyclones and inertial demisters following venturi scrubbers, or (2) in stacks having tangential inlets or other duct configurations which tend to induce swirling; in these instances, the presence or absence of cyclonic flow at the sampling location must be determined. The following techniques are acceptable for this determination.

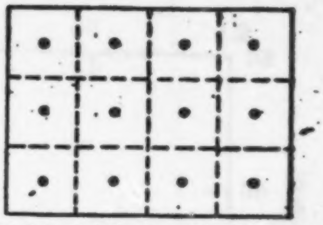

Figure 1-4. Example showing rectangular stack cross section divided into 12 equal areas, with a traverse point at centroid of each area.

Level and zero the manometer. Connect a Type S pitot tube to the manometer. Position the Type S pitot tube at each traverse point, in succession, so that the planes of the face openings of the pitot tube are perpendicular to the stack cross-sectional plane: when the Type S pitot tube is in this position, it is at "0° reference." Note the differential pressure (Δp) reading at each traverse point. If a null (zero) pitot reading is obtained at 0° reference at a given traverse point, an acceptable flow condition exists at that point. If the pitot reading is not zero at 0° reference, rotate the pitot tube (up to ±90° yaw angle), until a null reading is obtained. Carefully determine and record the value of the rotation angle (α) to the nearest degree. After the null technique has been applied at each traverse point, calculate the average of the absolute values of α; assign α values of 0° to those points for which no rotation was required, and include these in the overall average. If the average value of α is greater than 10°, the overall flow condition in the stack is unacceptable and alternative methodology, subject to the approval of the Administrator, must be used to perform accurate sample and velocity traverses.

3. *Bibliography*

1. Determining Dust Concentration in a Gas Stream. ASME. Performance Test Code No. 27. New York. 1957.

2. Devorkin, Howard, et al. Air Pollution Source Testing Manual. Air Pollution Control District. Los Angeles, CA. November 1963.

3. Methods for Determination of Velocity, Volume, Dust and Mist Content of Gases. Western Precipitation Division of Joy Manufacturing Co. Los Angeles, CA. Bulletin WP-50. 1968.

4. Standard Method for Sampling Stacks for Particulate Matter. In: 1971 Book of ASTM Standards, Part 23. ASTM Designation D-2928-71. Philadelphia, Pa. 1971.

5. Hanson, H. A., et al. Particulate Sampling Strategies for Large Power Plants Including Nonuniform Flow. USEPA, ORD, ESRL, Research Triangle Park, N.C. EPA-600/2-76-170. June 1976.

6. Entropy Environmentalists, Inc. Determination of the Optimum Number of Sampling Points: An Analysis of Method 1 Criteria. Environmental Protection Agency. Research Triangle Park, N.C. EPA Contract No. 68-01-3172, Task 7.

METHOD 2—DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE (TYPE S PITOT TUBE)

1. *Principle and Applicability*

1.1 Principle. The average gas velocity in a stack is determined from the gas density and from measurement of the average velocity head with a Type S (Stausscheibe or reverse type) pitot tube.

1.2 Applicability. This method is applicable for measurement of the average velocity of a gas stream and for quantifying gas flow.

This procedure is not applicable at measurement sites which fail to meet the criteria of Method 1, Section 2.1. Also, the method cannot be used for direct measurement in cyclonic or swirling gas streams; Section 2.4 of Method 1 shows how to determine cyclonic or swirling flow conditions. When unacceptable conditions exist, alternative procedures, subject to the approval of the Administrator, U.S. Environmental Protection Agency, must be employed to make accurate flow rate determinations; examples of such alternative procedures are: (1) to install straightening vanes; (2) to calculate the total volumetric flow rate stoichiometrically, or (3) to move to another measurement site at which the flow is acceptable.

2. *Apparatus*

Specifications for the apparatus are given below. Any other apparatus that has been demonstrated (subject to approval of the Administrator) to be capable of meeting the specifications will be considered acceptable.

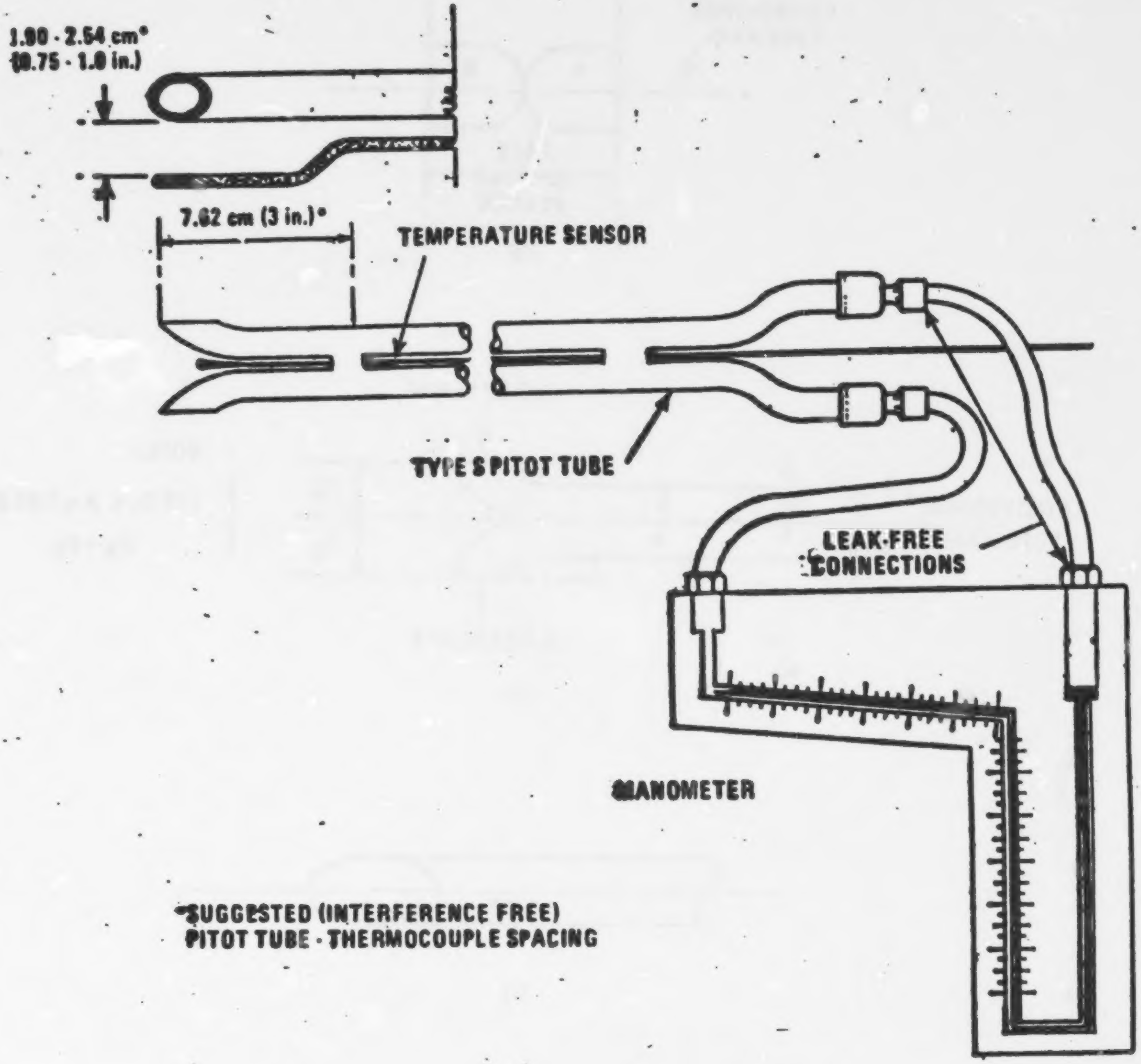
1.90 - 2.54 cm*
(0.75 - 1.0 in.)
7.62 cm (3 in.)*
TEMPERATURE SENSOR
TYPE S PITOT TUBE
LEAK-FREE CONNECTIONS
MANOMETER
*SUGGESTED (INTERFERENCE FREE) PITOT TUBE - THERMOCOUPLE SPACING

Figure 2-1. Type S pitot tube manometer assembly.

2.1 Type S Pitot Tube. The Type S pitot tube (Figure 2-1) shall be made of metal tubing (e.g., stainless steel). It is recommended that the external tubing diameter (dimension D_t, Figure 2-2b) be between 0.48 and 0.95 centimeters (3/16 and 3/8 inch). There shall be an equal distance from the base of each leg of the pitot tube to its face-opening plane (dimensions P_A and P_B, Figure 2-2b); it is recommended that this distance be between 1.05 and 1.50 times the external tubing diameter. The face openings of the pitot tube shall, preferably, be aligned as shown in Figure 2-2; however, slight misalignments of the openings are permissible (see Figure 2-3).

The Type S pitot tube shall have a known coefficient, determined as outlined in Section 4. An identification number shall be assigned to the pitot tube; this number shall be permanently marked or engraved on the body of the tube.

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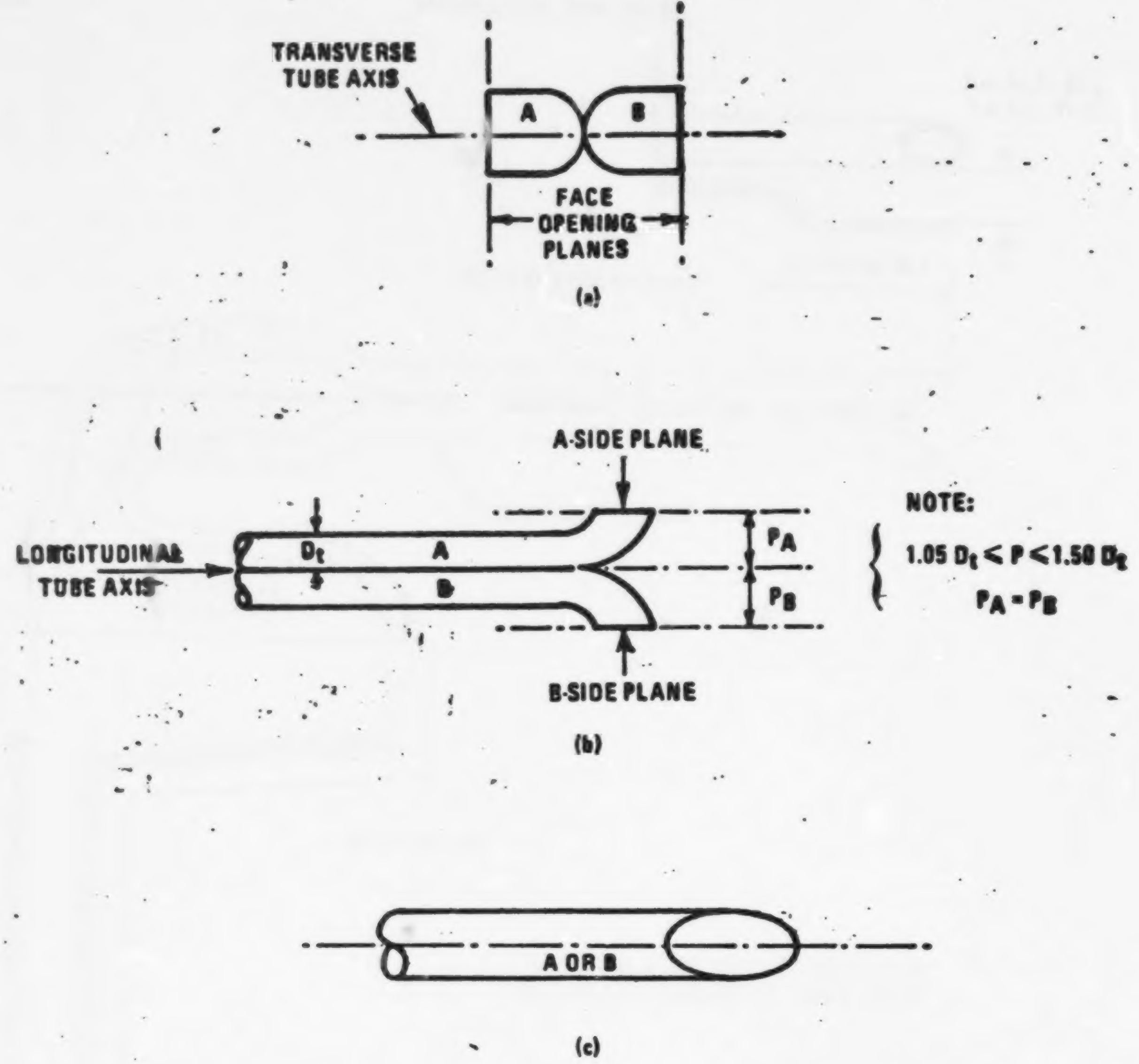

TRANSVERSE TUBE AXIS
A
B
FACE OPENING PLANES
(a)
A-SIDE PLANE
LONGITUDINAL TUBE AXIS
D_t
A
B
P_A
P_B
NOTE:
$1.05\ D_t < P < 1.50\ D_t$
$P_A = P_B$
B-SIDE PLANE
(b)
A OR B
(c)

Figure 2-2. Properly constructed Type S pitot tube, shown in: (a) end view; face opening planes perpendicular to transverse axis; (b) top view; face opening planes parallel to longitudinal axis; (c) side view; both legs of equal length and centerlines coincident, when viewed from both sides. Baseline coefficient values of 0.84 may be assigned to pitot tubes constructed this way.

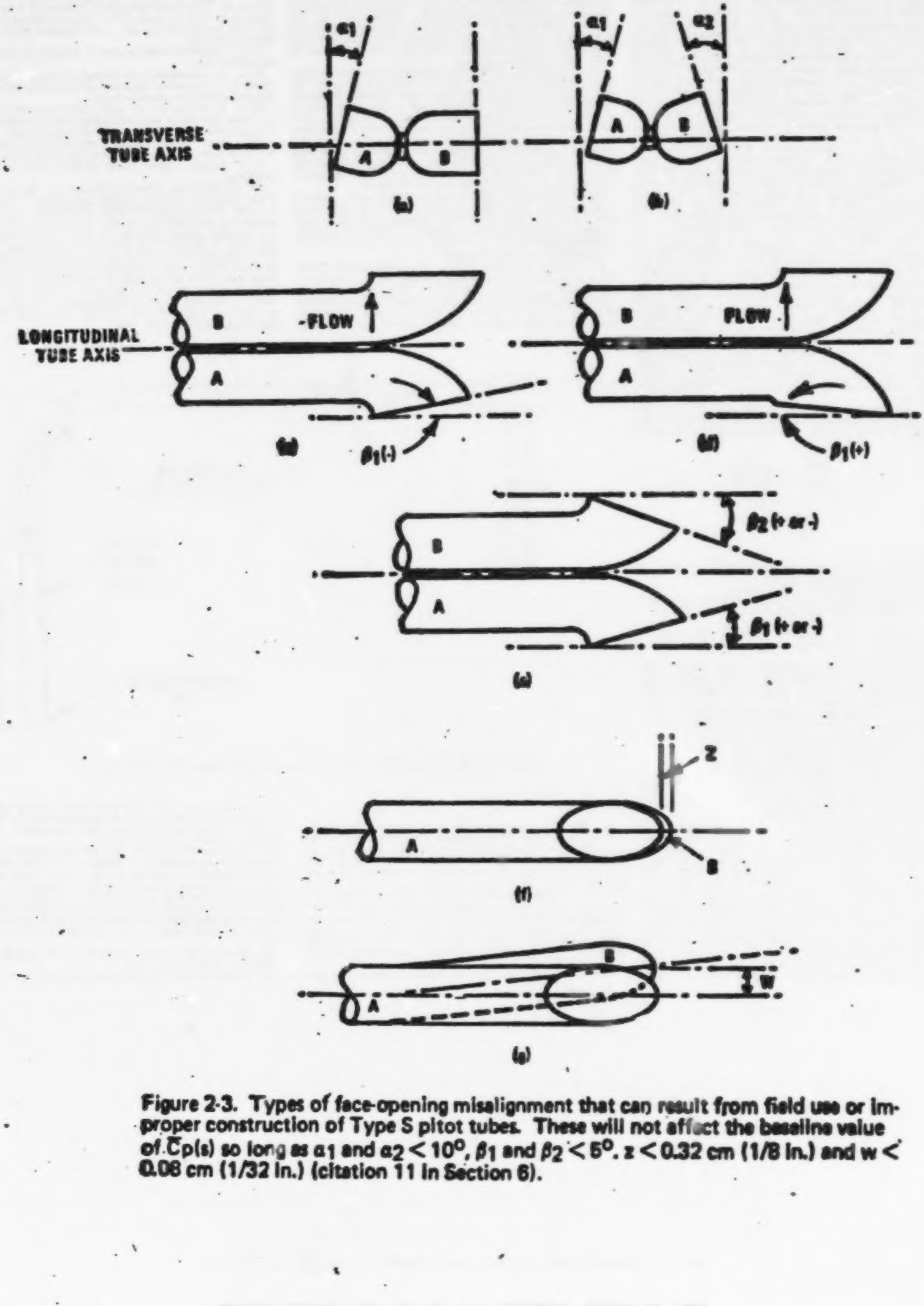

α1
α1
α2
TRANSVERSE TUBE AXIS
A
B
(a)
(b)
LONGITUDINAL TUBE AXIS
B
A
FLOW
(c)
β1(-)
(d)
β1(+)
B
A
β2 (+ or -)
β1 (+ or -)
(e)
Z
A
B
(f)
B
A
W
(g)

Figure 2-3. Types of face-opening misalignment that can result from field use or improper construction of Type S pitot tubes. These will not affect the baseline value of $\bar{C}_p(s)$ so long as α_1 and $\alpha_2 < 10^\circ$, β_1 and $\beta_2 < 5^\circ$, $z < 0.32$ cm (1/8 in.) and $w < 0.08$ cm (1/32 in.) (citation 11 in Section 6).

A standard pitot tube may be used instead of a Type S, provided that it meets the specifications of Sections 2.7 and 4.2; note, however, that the static and impact pressure holes of standard pitot tubes are susceptible to plugging in particulate-laden gas streams. Therefore, whenever a standard pitot tube is used to perform a traverse, adequate proof must be furnished that the openings of the pitot tube have not plugged up during the traverse period; this can be done by taking a velocity head (Δp) reading at the final traverse point, cleaning out the impact and static holes of the standard pitot tube by "back-purging" with pressurized air, and then taking another Δp reading. If the Δp readings made before and after the air purge are the same (±5 percent), the traverse is acceptable. Otherwise, reject the run. Note that if Δp at the final traverse point is unsuitably low, another point may be selected. If "back-purging" at regular intervals is part of the procedure, then comparative Δp readings shall be taken, as above, for the last two back purges at which suitably high Δp readings are observed.

2.2 Differential Pressure Gauge. An inclined manometer or equivalent device is used. Most sampling trains are equipped with a 10-in. (water column) inclined-vertical manometer, having 0.01-in. H_2O divisions on the 0- to 1-in. inclined scale, and 0.1-in. H_2O divisions on the 1- to 10-in. vertical scale. This type of manometer (or other gauge of equivalent sensitivity) is satisfactory for the measurement of Δp values as low as 1.3 mm (0.05 in.) H_2O. However, a differential pressure gauge of greater sensitivity shall be used (subject to the approval of the Administrator), if any of the following is found to be true: (1) the arithmetic average of all Δp readings at the traverse points in the stack is less than 1.3 mm (0.05 in.) H_2O; (2) for traverses of 12 or more points, more than 10 percent of the individual Δp readings are below 1.3 mm (0.05 in.) H_2O; (3) for traverses of fewer than 12 points, more than one Δp reading is below 1.3 mm (0.05 in.) H_2O. Citation 18 in Section 6 describes commercially available instrumentation for the measurement of low-range gas velocities.

As an alternative to criteria (1) through (3) above, the following calculation may be performed to determine the necessity of using a more sensitive differential pressure gauge:

$$T=\frac{\sum_{i=1}^{n}\sqrt{\Delta p_i+K}}{\sum_{i=1}^{n}\sqrt{\Delta p_i}}$$

where:

Δp_i = Individual velocity head reading at a traverse point, mm H_2O (in. H_2O).

n = Total number of traverse points.

K = 0.13 mm H_2O when metric units are used and 0.005 in H_2O when English units are used.

If T is greater than 1.05, the velocity head data are unacceptable and a more sensitive differential pressure gauge must be used.

NOTE.—If differential pressure gauges other than inclined manometers are used (e.g., magnehelic gauges), their calibration must be checked after each test series. To check the calibration of a differential pressure gauge, compare Δp readings of the gauge with those of a gauge-oil manometer at a minimum of three points, approximately representing the range of Δp values in the stack. If, at each point, the values of Δp as read by the differential pressure gauge and gauge-oil manometer agree to within 5 percent, the differential pressure gauge shall be considered to be in proper calibration. Otherwise, the test series shall either be voided, or procedures to adjust the measured Δp values and final results shall be used, subject to the approval of the Administrator.

2.3 Temperature Gauge. A thermocouple, liquid-filled bulb thermometer, bimetallic thermometer, mercury-in-glass thermometer, or other gauge capable of measuring temperature to within 1.5 percent of the minimum absolute stack temperature shall be used. The temperature gauge shall be attached to the pitot tube such that the sensor tip does not touch any metal; the gauge shall be in an interference-free arrangement with respect to the pitot tube face openings (see Figure 2-1 and also Figure 2-7 in Section 4). Alternate positions may be used if the pitot tube-temperature gauge system is calibrated according to the procedure of Section 4. Provided that a difference of not more than 1 percent in the average velocity measurement is introduced, the temperature gauge need not be attached to the pitot tube; this alternative is subject to the approval of the Administrator.

2.4 Pressure Probe and Gauge. A piezometer tube and mercury- or water-filled U-tube manometer capable of measuring stack pressure to within 2.5 mm (0.1 in.) Hg is used. The static tap of a standard type pitot tube or one leg of a Type S pitot tube with the face openings planes positioned parallel to the gas flow may also be used as the pressure probe.

2.5 Barometer. A mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg) may be used. In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and the sampling point shall be applied at a rate of minus 2.5 mm (0.1 in.) Hg per 30-meter (100 foot) elevation increase, or vice-versa for elevation decrease.

2.6 Gas Density Determination Equipment. Method 3 equipment, if needed (see Section 3.6), to determine the stack gas dry molecular weight, and Reference Method 4 or Method 5 equipment for moisture content determination; other methods may be used subject to approval of the Administrator.

2.7 Calibration Pitot Tube. When calibration of the Type S pitot tube is necessary (see Section 4), a standard pitot tube is used as a reference. The standard pitot tube shall, preferably, have a known coefficient, obtained either (1) directly from the National Bureau of Standards, Route 270, Quince Orchard Road, Gaithersburg, Maryland, or (2) by calibration against another standard pitot tube with an NBS-traceable coefficient. Alternatively, a standard pitot tube designed according to the criteria given in 2.7.1 through 2.7.5 below and illustrated in Figure 2-4 (see also Citations 7, 9, and 17 in Section 6) may be used. Pitot tubes designed according to these specifications will have baseline coefficients of about 0.99±0.01.

2.7.1 Hemispherical (shown in Figure 2-4), ellipsoidal, or conical tip.

2.7.2 A minimum of six diameters straight run (based upon *D*, the external diameter of the tube) between the tip and the static pressure holes.

2.7.3 A minimum of eight diameters straight run between the static pressure holes and the centerline of the external tube, following the 90 degree bend.

2.7.4 Static pressure holes of equal size (approximately 0.1 *D*), equally spaced in a piezometer ring configuration.

2.7.5 Ninety degree bend, with curved or mitered junction.

2.8 Differential Pressure Gauge for Type S Pitot Tube Calibration. An inclined manometer or equivalent is used. If the single-velocity calibration technique is employed (see Section 4.1.2.3), the calibration differential pressure gauge shall be readable to the nearest 0.13 mm H_2O (0.005 in. H_2O). For multivelocity calibrations, the gauge shall be readable to the nearest 0.13 mm H_2O (0.005 in H_2O) for Δp values between 1.3 and 25 mm H_2O (0.05 and 1.0 in. H_2O), and to the nearest 1.3 mm H_2O (0.05 in. H_2O) for Δp values above 25 mm H_2O (1.0 in. H_2O). A special, more sensitive gauge will be required to read Δp values below 1.3 mm H_2O (0.05 in. H_2O) (see Citation 18 in Section 6).

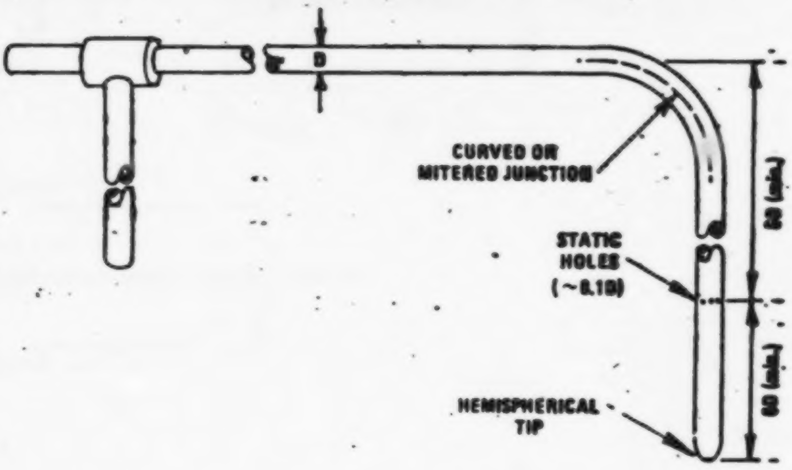


Figure 2-4. Standard pitot tube design specifications.

3. *Procedure*

3.1 Set up the apparatus as shown in Figure 2-1. Capillary tubing or surge tanks installed between the manometer and pitot tube may be used to dampen Δp fluctuations. It is recommended, but not required, that a pretest leak-check be conducted, as follows: (1) blow through the pitot impact opening until at least 7.6 cm (3 in.) H_2O velocity pressure registers on the manometer; then, close off the impact opening. The pressure shall remain stable for at least 15 seconds; (2) do the same for the static pressure side, except using suction to obtain the minimum of 7.6 cm (3 in.) H_2O. Other leak-check procedures, subject to the approval of the Administrator, may be used.

3.2 Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse. Record all necessary data as shown in the example data sheet (Figure 2-6).

3.3 Measure the velocity head and temperature at the traverse points specified by Method 1. Ensure that the proper differential pressure gauge is being used for the range of Δp values encountered (see Section 2.2). If it is necessary to change to a more sensitive gauge, do so, and remeasure the Δp and temperature readings at each traverse point. Conduct a post-test leak-check (mandatory), as described in Section 3.1 above, to validate the traverse run.

3.4 Measure the static pressure in the stack. One reading is usually adequate.

3.5 Determine the atmospheric pressure.

PLANT ____________________

DATE ____________ RUN NO. ____________

STACK DIAMETER OR DIMENSIONS, m(in.) ____________

BAROMETRIC PRESSURE, mm Hg (in. Hg) ____________

CROSS SECTIONAL AREA, m^2(ft^2) ____________

OPERATORS ____________________

PITOT TUBE I.D. NO. ____________________

AVG. COEFFICIENT, C_p = ____________

LAST DATE CALIBRATED ____________

SCHEMATIC OF STACK CROSS SECTION

Traverse Pt. No.	Vel. Hd., Δp mm (in.) H_2O	Stack Temperature		P_g mm Hg (in.Hg)	$\sqrt{\Delta p}$
		t_s, °C (°F)	T_s, °K (°R)		
		Average			

Figure 2-5. Velocity traverse data.

3.6 Determine the stack gas dry molecular weight. For combustion processes or processes that emit essentially CO_2, O_2, CO, and N_2, use Method 3. For processes emitting essentially air, an analysis need not be conducted; use a dry molecular weight of 29.0. For other processes, other methods, subject to the approval of the Administrator, must be used.

3.7 Obtain the moisture content from Reference Method 4 (or equivalent) or from Method 5.

3.8 Determine the cross-sectional area of the stack or duct at the sampling location. Whenever possible, physically measure the stack dimensions rather than using blueprints.

4. Calibration

4.1 Type S Pitot Tube. Before its initial use, carefully examine the Type S pitot tube in top, side, and end views to verify that the face openings of the tube are aligned within the specifications illustrated in Figure 2-2 or 2-3. The pitot tube shall not be used if it fails to meet these alignment specifications.

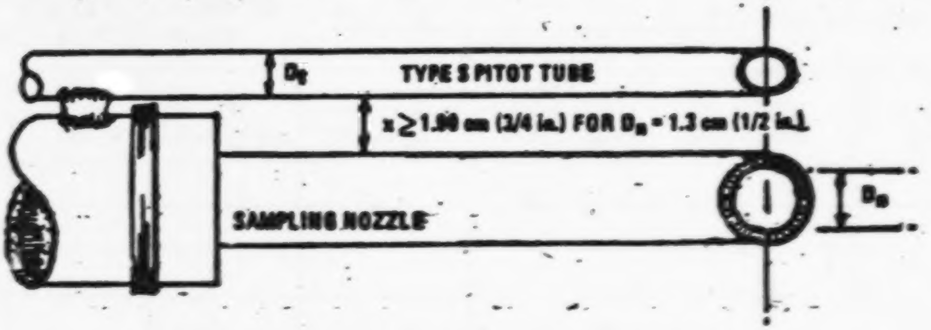
After verifying the face opening alignment, measure and record the following dimensions of the pitot tube: (a) the external tubing diameter (dimension D_t, Figure 2-2b); and (b) the base-to-opening plane distances (dimensions P_A and P_B, Figure 2-2b). If D_t is between 0.48 and 0.95 cm (3/16 and 3/8 in.) and if P_A and P_B are equal and between 1.05 and 1.50 D_t, there are two possible options: (1) the pitot tube may be calibrated according to the procedure outlined in Sections 4.1.2 through 4.1.5 below, or (2) a baseline (isolated tube) coefficient value of 0.84 may be assigned to the pitot tube. Note, however, that if the pitot tube is part of an assembly, calibration may still be required, despite knowledge of the baseline coefficient value (see Section 4.1.1).

If D_t, P_A, and P_B are outside the specified limits, the pitot tube must be calibrated as outlined in 4.1.2 through 4.1.5 below.

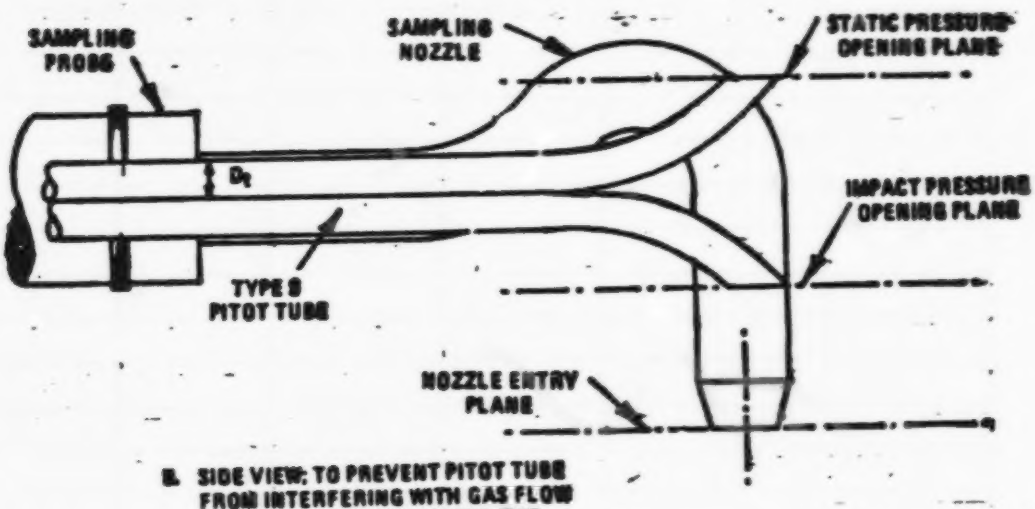
4.1.1 Type S Pitot Tube Assemblies. During sample and velocity traverses, the isolated Type S pitot tube is not always used; in many instances, the pitot tube is used in combination with other source-sampling components (thermocouple, sampling probe, nozzle) as part of an "assembly." The presence of other sampling components can sometimes affect the baseline value of the Type S pitot tube coefficient (Citation 9 in Section 6); therefore an assigned (or otherwise known) baseline coefficient value may or may not be valid for a given assembly. The baseline and assembly coefficient values will be identical only when the relative placement of the components in the assembly is such that aerodynamic interference effects are eliminated. Figures 2-6 through 2-8 illustrate interference-free component arrangements for Type S pitot tubes having external tubing diameters between 0.48 and 0.95 cm (3/16 and 3/8 in.). Type S pitot tube assemblies that fail to meet any or all of the specifications of Figures 2-6 through 2-8 shall be calibrated according to the procedure outlined in Sections 4.1.2 through 4.1.5 below, and prior to calibration, the values of the intercomponent spacings (pitot-nozzle, pitot-thermocouple, pitot-probe sheath) shall be measured and recorded.

NOTE.—Do not use any Type S pitot tube assembly which is constructed such that the impact pressure opening plane of the pitot tube is below the entry plane of the nozzle (see Figure 2-6b).

4.1.2 Calibration Setup. If the Type S pitot tube is to be calibrated, one leg of the tube shall be permanently marked A, and the other, B. Calibration shall be done in a flow system having the following essential design features:



A. BOTTOM VIEW; SHOWING MINIMUM PITOT-NOZZLE SEPARATION.



B. SIDE VIEW; TO PREVENT PITOT TUBE FROM INTERFERING WITH GAS FLOW STREAMLINES APPROACHING THE NOZZLE, THE IMPACT PRESSURE OPENING PLANE OF THE PITOT TUBE SHALL BE EVEN WITH OR ABOVE THE NOZZLE ENTRY PLANE.

Figure 2-6. Proper pitot tube - sampling nozzle configuration to prevent aerodynamic interference; buttonhook - type nozzle; centers of nozzle and pitot opening aligned; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

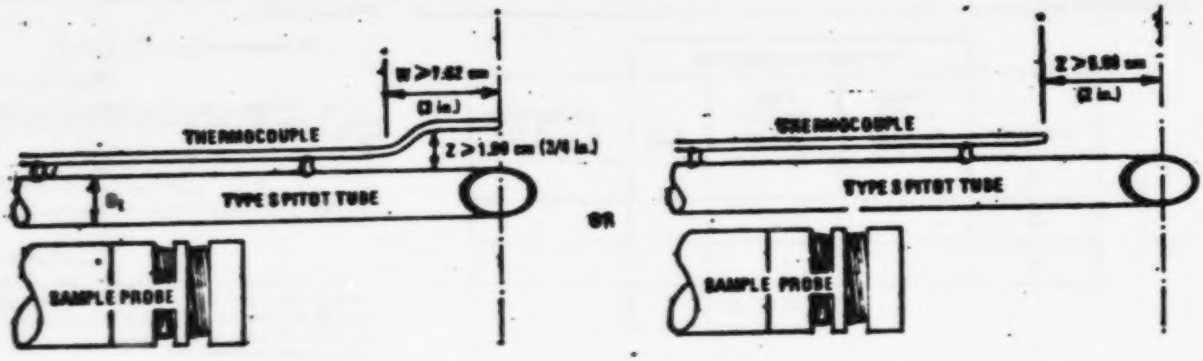


Figure 2-7. Proper thermocouple placement to prevent interference; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

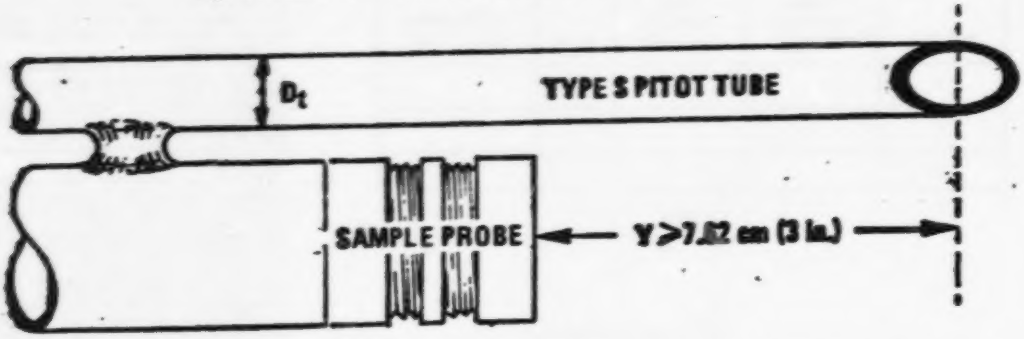


Figure 2-8. Minimum pitot-sample probe separation needed to prevent interference; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

4.1.2.1 The flowing gas stream must be confined to a duct of definite cross-sectional area, either circular or rectangular. For circular cross-sections, the minimum duct diameter shall be 30.5 cm (12 in.); for rectangular cross-sections, the width (shorter side) shall be at least 25.4 cm (10 in.).

4.1.2.2 The cross-sectional area of the calibration duct must be constant over a distance of 10 or more duct diameters. For a rectangular cross-section, use an equivalent diameter, calculated from the following equation, to determine the number of duct diameters:

$$D_e = \frac{2LW}{(L+W)}$$

Equation 2-1

where:

D_e = Equivalent diameter
L = Length
W = Width

To ensure the presence of stable, fully developed flow patterns at the calibration site, or "test section," the site must be located at least eight diameters downstream and two diameters upstream from the nearest disturbances.

NOTE.—The eight- and two-diameter criteria are not absolute; other test section locations may be used (subject to approval of the Administrator), provided that the flow at the test site is stable and demonstrably parallel to the duct axis.

4.1.2.3 The flow system shall have the capacity to generate a test-section velocity around 915 m/min (3,000 ft/min). This velocity must be constant with time to guarantee steady flow during calibration. Note that Type S pitot tube coefficients obtained by single-velocity calibration at 915 m/min (3,000 ft/min) will generally be valid to within ±3 percent for the measurement of velocities above 305 m/min (1,000 ft/min) and to within ±5 to 6 percent for the measurement of velocities between 180 and 305 m/min (600 and 1,000 ft/min). If a more precise correlation between C_p and velocity is desired, the flow system shall have the capacity to generate at least four distinct, time-invariant test-section velocities covering the velocity range from 180 to 1,525 m/min (600 to 5,000 ft/min), and calibration data shall be taken at regular velocity intervals over this range (see Citations 9 and 14 in Section 6 for details).

4.1.2.4 Two entry ports, one each for the standard and Type S pitot tubes, shall be cut in the test section; the standard pitot entry port shall be located slightly downstream of the Type S port, so that the standard and Type S impact openings will lie in the same cross-sectional plane during calibration. To facilitate alignment of the pitot tubes during calibration, it is advisable that the test section be constructed of plexiglas or some other transparent material.

4.1.3 Calibration Procedure. Note that this procedure is a general one and must not be used without first referring to the special considerations presented in Section 4.1.5. Note also that this procedure applies only to single-velocity calibration. To obtain calibration data for the A and B sides of the Type S pitot tube, proceed as follows:

4.1.3.1 Make sure that the manometer is properly filled and that the oil is free from contamination and is of the proper density. Inspect and leak-check all pitot lines; repair or replace if necessary.

4.1.3.2 Level and zero the manometer. Turn on the fan and allow the flow to stabilize. Seal the Type S entry port.

4.1.3.3 Ensure that the manometer is level and zeroed. Position the standard pitot tube at the calibration point (determined as outlined in Section 4.1.5.1), and align the tube so that its tip is pointed directly into the flow. Particular care should be taken in aligning the tube to avoid yaw and pitch angles. Make sure that the entry port surrounding the tube is properly sealed.

4.1.3.4 Read Δp_{std} and record its value in a data table similar to the one shown in Figure 2-9. Remove the standard pitot tube from the duct and disconnect it from the manometer. Seal the standard entry port.

4.1.3.5 Connect the Type S pitot tube to the manometer. Open the Type S entry port. Check the manometer level and zero. Insert and align the Type S pitot tube so that its A side impact opening is at the same point as was the standard pitot tube and is pointed directly into the flow. Make sure that the entry port surrounding the tube is properly sealed.

4.1.3.6 Read Δp_s and enter its value in the data table. Remove the Type S pitot tube from the duct and disconnect it from the manometer.

4.1.3.7 Repeat steps 4.1.3.3 through 4.1.3.6 above until three pairs of Δp readings have been obtained.

4.1.3.8 Repeat steps 4.1.3.3 through 4.1.3.7 above for the B side of the Type S pitot tube.

4.1.3.9 Perform calculations, as described in Section 4.1.4 below.

4.1.4 Calculations.

4.1.4.1 For each of the six pairs of Δp readings (i.e., three from side A and three from side B) obtained in Section 4.1.3 above, calculate the value of the Type S pitot tube coefficient as follows:

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PITOT TUBE IDENTIFICATION NUMBER: ______________ DATE: __________

CALIBRATED BY: ______________________________

"A" SIDE CALIBRATION

RUN NO.	Δp_{std} cm H_2O (in. H_2O)	$\Delta p_{(s)}$ cm H_2O (in. H_2O)	$C_{p(s)}$	DEVIATION $C_{p(s)} - \bar{C}_p(A)$
1				
2				
3				
		$\bar{C}_p$ (SIDE A)		

"B" SIDE CALIBRATION

RUN NO.	Δp_{std} cm H_2O (in. H_2O)	$\Delta p_{(s)}$ cm H_2O (in. H_2O)	$C_{p(s)}$	DEVIATION $C_{p(s)} - \bar{C}_p(B)$
1				
2				
3				
		$\bar{C}_p$ (SIDE B)		

$$\text{AVERAGE DEVIATION} = \sigma(\text{A OR B}) = \frac{\sum_{1}^{3} \left| C_{p(s)} - \bar{C}_p(\text{A OR B}) \right|}{3} \longleftarrow \text{MUST BE} < 0.01$$

$$\left| \bar{C}_p(\text{SIDE A}) - \bar{C}_p(\text{SIDE B}) \right| \longleftarrow \text{MUST BE} < 0.01$$

Figure 2-9. Pitot tube calibration data.

$$C_{p(s)} = C_{p(std)} \sqrt{\frac{\Delta p_{std}}{\Delta p_s}}$$

Equation 2-2

where

$C_{p(s)}$ = Type S pitot tube coefficient

$C_{p(std)}$ = Standard pitot tube coefficient; use 0.99 if the coefficient is unknown and the tube is designed according to the criteria of Sections 2.7.1 to 2.7.5 of this method.

Δp_{std} = Velocity head measured by the standard pitot tube, cm H_2O (in. H_2O)

Δp_s = Velocity head measured by the Type S pitot tube, cm H_2O (in. H_2O)

4.1.4.2 Calculate $\bar{C}_p$ (side A), the mean A-side coefficient, and $\bar{C}_p$ (side B), the mean B-side coefficient; calculate the difference between these two average values.

4.1.4.3 Calculate the deviation of each of the three A-side values of $C_{p(s)}$ from $\bar{C}_p$ (side A), and the deviation of each B-side value of $C_{p(s)}$ from $\bar{C}_p$ (side B). Use the following equation:

$$\text{Deviation} = C_{p(s)} - \bar{C}_p(\text{A or B})$$

Equation 2-3

4.1.4.4 Calculate σ, the average deviation from the mean, for both the A and B sides of the pitot tube. Use the following equation:

$$\sigma(\text{side A or B}) = \frac{\sum_{1}^{3} |C_{p(s)} - \bar{C}_p(A \text{ or } B)|}{3}$$

Equation 2-4

4.1.4.5 Use the Type S pitot tube only if the values of σ (side A) and σ (side B) are less than or equal to 0.01 and if the absolute value of the difference between $\bar{C}_p$ (A) and $\bar{C}_p$ (B) is 0.01 or less.

4.1.5 Special considerations.

4.1.5.1 Selection of calibration point.

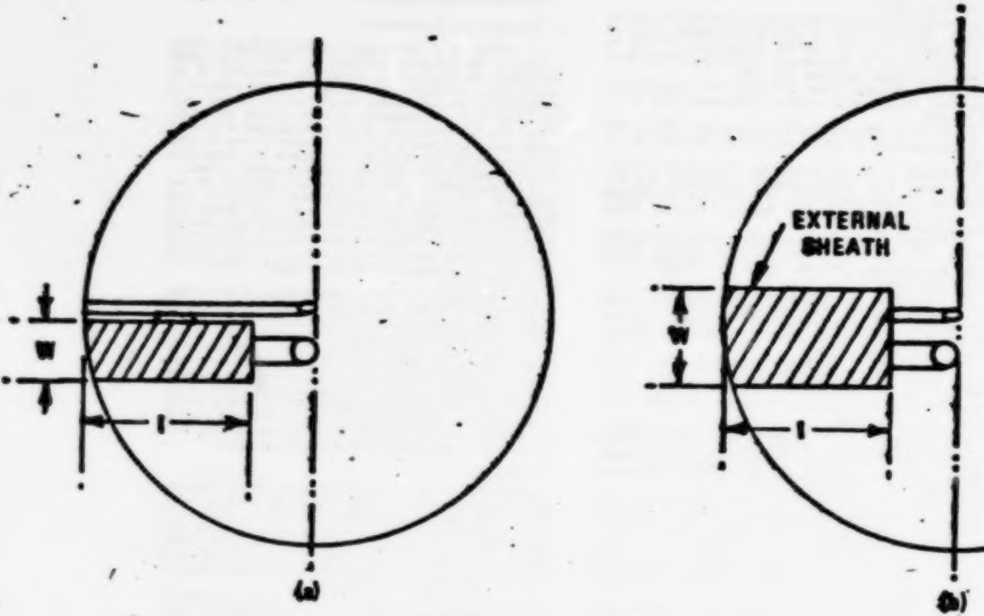
4.1.5.1.1 When an isolated Type S pitot tube is calibrated, select a calibration point at or near the center of the duct, and follow the procedures outlined in Sections 4.1.3 and 4.1.4 above. The Type S pitot coefficients so obtained, i.e., $\bar{C}_p$ (side A) and $\bar{C}_p$ (side B), will be valid, so long as either: (1) the isolated pitot tube is used; or (2) the pitot tube is used with other components (nozzle, thermocouple, sample probe) in an arrangement that is free from aerodynamic interference effects (see Figures 2-4 through 2-6).

4.1.5.1.2 For Type S pitot tube-thermocouple combinations (without sample probe), select a calibration point at or near the center of the duct, and follow the procedures outlined in Sections 4.1.3 and 4.1.4 above. The coefficients so obtained will be valid so long as the pitot tube-thermocouple combination is used by itself or with other components in an interference-free arrangement (Figures 2-5 and 2-6).

4.1.5.1.3 For assemblies with sample probes, the calibration point should be located at or near the center of the duct; however, insertion of a probe sheath into a small duct may cause significant cross-sectional area blockage and yield incorrect coefficient values (Citation 9 in Section 6). Therefore, to minimize the blockage effect, the calibration point may be a few inches off-center if necessary. The actual blockage effect will be negligible when the theoretical blockage, as determined by a projected-area model of the probe sheath, is 2 percent or less of the duct cross-sectional area for assemblies without external sheaths (Figure 2-10a), and 3 percent or less for assemblies with external sheaths (Figure 2-10b).

4.1.5.2 For those probe assemblies in which pitot tube-nozzle interference is a factor (i.e., those in which the pitot-nozzle separation distance fails to meet the specification illustrated in Figure 2-6a), the value of $C_{p(s)}$ depends upon the amount of free-space between the tube and nozzle, and therefore is a function of nozzle size. In these instances, separate calibrations shall be performed with each of the commonly used nozzle sizes in place. Note that the single-velocity calibration technique is acceptable for this purpose, even though the larger nozzle sizes (>0.635 cm or ¼ in.) are not ordinarily used for isokinetic sampling at velocities around 915 m/min (3,000 ft/min), which is the calibration velocity; note also that it is not necessary to draw an isokinetic sample during calibration (see Citation 19 in Section 6).

4.1.5.3 For a probe assembly constructed such that its pitot tube is always used in the same orientation, only one side of the pitot tube need be calibrated (the side which will face the flow). The pitot tube must still meet the alignment specifications of Figure 2-2 or 2-3, however, and must have an average deviation (σ) value of 0.01 or less (see Section 4.1.4.4).



$$\text{ESTIMATED SHEATH BLOCKAGE (\%)} = \left[\frac{l \times W}{\text{DUCT AREA}}\right] \times 100$$

Figure 2-10. Projected-area models for typical pitot tube assemblies.

4.1.6 Field Use and Recalibration.

4.1.6.1 Field Use.

4.1.6.1.1 When a Type S pitot tube (isolated tube or assembly) is used in the field, the appropriate coefficient value (whether assigned or obtained by calibration) shall be used to perform velocity calculations. For calibrated Type S pitot tubes, the A side coefficient shall be used when the A side of the tube faces the flow, and the B side coefficient shall be used when the B side faces the flow; alternatively, the arithmetic average of the A and B side coefficient values may be used, irrespective of which side faces the flow.

4.1.6.1.2 When a probe assembly is used to sample a small duct (12 to 36 in. in diameter), the probe sheath sometimes blocks a significant part of the duct cross-section, causing a reduction in the effective value of $C_{p(s)}$. Consult Citation 9 in Section 6 for details. Conventional pitot-sampling probe assemblies are not recommended for use in ducts having inside diameters smaller than 12 inches (Citation 16 in Section 6).

4.1.6.2 Recalibration.

4.1.6.2.1 Isolated Pitot Tubes. After each field use, the pitot tube shall be carefully reexamined in top, side, and end views. If the pitot face openings are still aligned within the specifications illustrated in Figure 2-2 or 2-3, it can be assumed that the baseline coefficient of the pitot tube has not changed. If, however, the tube has been damaged to the extent that it no longer meets the specifications of Figure 2-2 or 2-3, the damage shall either be repaired to restore proper alignment of the face openings or the tube shall be discarded.

4.1.6.2.2 Pitot Tube Assemblies. After each field use, check the face opening alignment of the pitot tube, as in Section 4.1.6.2.1; also, remeasure the intercomponent spacings of the assembly. If the intercomponent spacings have not changed and the face opening alignment is acceptable, it can be assumed that the coefficient of the assembly has not changed. If the face opening alignment is no longer within the specifications of Figures 2-2 or 2-3, either repair the damage or replace the pitot tube (calibrating the new assembly, if necessary). If the intercomponent spacings have changed, restore the original spacings or recalibrate the assembly.

4.2 Standard pitot tube (if applicable). If a standard pitot tube is used for the velocity traverse, the tube shall be constructed according to the criteria of Section 2.7 and shall be assigned a baseline coefficient value of 0.99. If the standard pitot tube is used as part of an assembly, the tube shall be in an interference-free arrangement (subject to the approval of the Administrator).

4.3 Temperature Gauges. After each field use, calibrate dial thermometers, liquid-filled bulb thermometers, thermocouple-potentiometer systems, and other gauges at a temperature within 10 percent of the average absolute stack temperature. For temperatures up to 405° C (761° F), use an ASTM mercury-in-glass reference thermometer, or equivalent, as a reference; alternatively, either a reference thermocouple and potentiometer (calibrated by NBS) or thermometric fixed points, e.g., ice bath and boiling water (corrected for barometric pressure) may be used. For temperatures above 405° C (761° F), use an NBS-calibrated reference thermocouple-potentiometer system or an alternate reference, subject to the approval of the Administrator.

If, during calibration, the absolute temperatures measured with the gauge being calibrated and the reference gauge agree within 1.5 percent, the temperature data taken in the field shall be considered valid. Otherwise, the pollutant emission test shall either be considered invalid or adjustments (if appropriate) of the test results shall be made, subject to the approval of the Administrator.

4.4 Barometer. Calibrate the barometer used against a mercury barometer.

5. *Calculations*

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation.

5.1 Nomenclature

A = Cross-sectional area of stack, m² (ft²).

B_{ws} = Water vapor in the gas stream (from Method 5 or Reference Method 4), proportion by volume.

C_p = Pitot tube coefficient, dimensionless.

K_p = Pitot tube constant,

$$34.97\ \frac{\text{m}}{\text{sec}}\left[\frac{(\text{g/g-mole})(\text{mm Hg})}{(^\circ\text{K})(\text{mm H}_2\text{O})}\right]^{1/2}$$

for the metric system and

$$85.49\ \frac{\text{ft}}{\text{sec}}\left[\frac{(\text{lb/lb-mole})(\text{in. Hg})}{(^\circ\text{R})(\text{in. H}_2\text{O})}\right]^{1/2}$$

for the English system.

M_d = Molecular weight of stack gas, dry basis (see Section 3.6) g/g-mole (lb/lb-mole).

M_s = Molecular weight of stack gas, wet basis, g/g-mole (lb/lb-mole).

$= M_d (1 - B_{ws}) + 18.0\ B_{ws}$ Equation 2-5

P_{bar} = Barometric pressure at measurement site, mm Hg (in. Hg).

P_g = Stack static pressure, mm Hg (in. Hg).

P_s = Absolute stack gas pressure, mm Hg (in. Hg).

$= P_{bar} + P_g$ Equation 2-6

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

Q_{sd} = Dry volumetric stack gas flow rate corrected to standard conditions, dscm/hr (dscf/hr).

t_s = Stack temperature, °C (°F).

T_s = Absolute stack temperature, °K (°R).

$= 273 + t_s$ for metric Equation 2-7

$= 460 + t_s$ for English Equation 2-8

T_{std} = Standard absolute temperature, 293 °K (528° R)

v_s = Average stack gas velocity, m/sec (ft/sec).

Δp = Velocity head of stack gas, mm H₂O (in. H₂O).

3,600 = Conversion factor, sec/hr.

18.0 = Molecular weight of water, g/g-mole (lb-lb-mole).

5.2 Average stack gas velocity.

$$v_s = K_p C_p (\sqrt{\Delta p})_{avg} \sqrt{\frac{T_{s(avg)}}{P_s M_s}}$$

Equation 2-9

5.3 Average stack gas dry volumetric flow rate.

$$Q_{sd} = 3{,}600 (1 - B_{ws}) v_s A \left(\frac{T_{std}}{T_{s(avg)}}\right)\left(\frac{P_s}{P_{std}}\right)$$

Equation 2-10

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1. Mark, L. S. Mechanical Engineers' Handbook. New York, McGraw-Hill Book Co., Inc. 1951.

2. Perry, J. H. Chemical Engineers' Handbook. New York. McGraw-Hill Book Co., Inc. 1960.

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METHOD 3—GAS ANALYSIS FOR CARBON DIOXIDE, OXYGEN, EXCESS AIR, AND DRY MOLECULAR WEIGHT

1. *Principle and Applicability*

1.1 Principle. A gas sample is extracted from a stack, by one of the following methods: (1) single-point, grab sampling; (2) single-point, integrated sampling; or (3) multi-point, integrated sampling. The gas sample is analyzed for percent carbon dioxide (CO_2), percent oxygen (O_2), and, if necessary, percent carbon monoxide (CO). If a dry molecular weight determination is to be made, either an Orsat or a Fyrite[1] analyzer may be used for the analysis; for excess air or emission rate correction factor determination, an Orsat analyzer must be used.

1.2 Applicability. This method is applicable for determining CO_2 and O_2 concentrations, excess air, and dry molecular weight of a sample from a gas stream of a fossil-fuel combustion process. The method may also be applicable to other processes where it has been determined that compounds other than CO_2, O_2, CO, and nitrogen (N_2) are not present in concentrations sufficient to affect the results.

Other methods, as well as modifications to the procedure described herein, are also applicable for some or all of the above determinations. Examples of specific methods and modifications include: (1) a multi-point sampling method using an Orsat analyzer to analyze individual grab samples obtained at each point; (2) a method using CO_2 or O_2 and stoichiometric calculations to determine dry molecular weight and excess air; (3) assigning a value of 30.0 for dry molecular weight, in lieu of actual measurements, for processes burning natural gas, coal, or oil. These methods and modifications may be used, but are subject to the approval of the Administrator.

2. *Apparatus*

As an alternative to the sampling apparatus and systems described herein, other sampling systems (e.g., liquid displacement) may be used provided such systems are capable of obtaining a representative sample and maintaining a constant sampling rate, and are otherwise capable of yielding acceptable results. Use of such systems is subject to the approval of the Administrator.

2.1 Grab Sampling (Figure 3-1).

2.1.1 Probe. The probe should be made of stainless steel or borosilicate glass tubing and should be equipped with an in-stack or out-stack filter to remove particulate matter (a plug of glass wool is satisfactory for this purpose). Any other material inert to O_2, CO_2, CO, and N_2 and resistant to temperature at sampling conditions may be used for the probe; examples of such material are aluminum, copper, quartz glass and Teflon.

2.1.2 Pump. A one-way squeeze bulb, or equivalent, is used to transport the gas sample to the analyzer.

2.2 Integrated Sampling (Figure 3-2).

2.2.1 Probe. A probe such as that described in Section 2.1.1 is suitable.

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[1] Mention of trade names or specific products does not constitute endorsement by the Environmental Protection Agency.

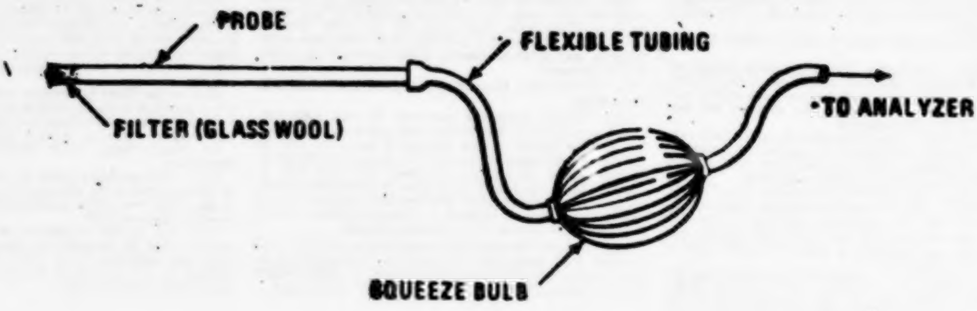
PROBE
FLEXIBLE TUBING
TO ANALYZER
FILTER (GLASS WOOL)
SQUEEZE BULB

Figure 3-1. Grab sampling train.

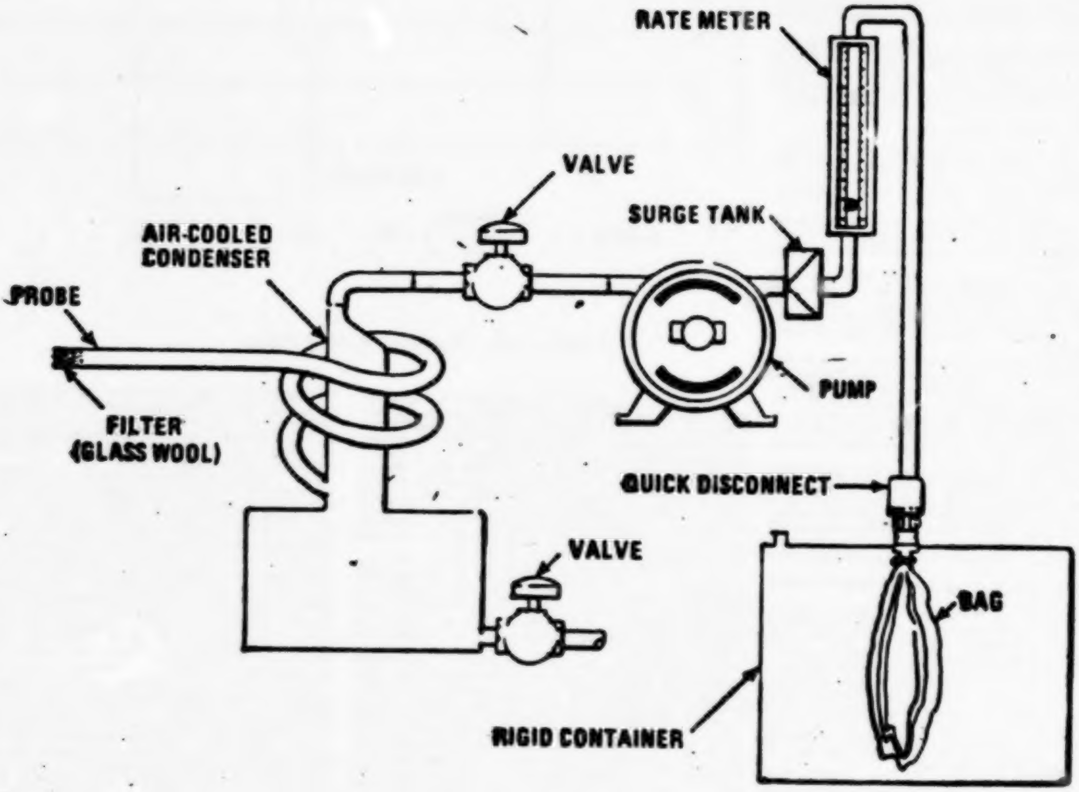
RATE METER
VALVE
SURGE TANK
AIR-COOLED CONDENSER
PROBE
PUMP
FILTER (GLASS WOOL)
QUICK DISCONNECT
VALVE
BAG
RIGID CONTAINER

Figure 3-2. Integrated gas-sampling train.

2.2.2 Condenser. An air-cooled or water-cooled condenser, or other condenser that will not remove O_2, CO_2, CO, and N_2, may be used to remove excess moisture which would interfere with the operation of the pump and flow meter.

2.2.3 Valve. A needle valve is used to adjust sample gas flow rate.

2.2.4 Pump. A leak-free, diaphragm-type pump, or equivalent, is used to transport sample gas to the flexible bag. Install a small surge tank between the pump and rate meter to eliminate the pulsation effect of the diaphragm pump on the rotameter.

2.2.5 Rate Meter. The rotameter, or equivalent rate meter, used should be capable of measuring flow rate to within ±2 percent of the selected flow rate. A flow rate range of 500 to 1000 cm^3/min is suggested.

2.2.6 Flexible Bag. Any leak-free plastic (e.g., Tedlar, Mylar, Teflon) or plastic-coated aluminum (e.g., aluminized Mylar) bag, or equivalent, having a capacity consistent with the selected flow rate and time length of the test run, may be used. A capacity in the range of 55 to 90 liters is suggested.

To leak-check the bag, connect it to a water manometer and pressurize the bag to 5 to 10 cm H_2O (2 to 4 in. H_2O). Allow to stand for 10 minutes. Any displacement in the water manometer indicates a leak. An alternative leak-check method is to pressurize the bag to 5 to 10 cm H_2O (2 to 4 in. H_2O) and allow to stand overnight. A deflated bag indicates a leak.

2.2.7 Pressure Gauge. A water-filled U-tube manometer, or equivalent, of about 28 cm (12 in.) is used for the flexible bag leak-check.

2.2.8 Vacuum Gauge. A mercury manometer, or equivalent, of at least 760 mm Hg (30 in. Hg) is used for the sampling train leak-check.

2.3 Analysis. For Orsat and Fyrite analyzer maintenance and operation procedures, follow the instructions recommended by the manufacturer, unless otherwise specified herein.

2.3.1 Dry Molecular Weight Determination. An Orsat analyzer or Fyrite type combustion gas analyzer may be used.

2.3.2 Emission Rate Correction Factor or Excess Air Determination. An Orsat analyzer must be used. For low CO_2 (less than 4.0 percent) or high O_2 (greater than 15.0 percent) concentrations, the measuring burette of the Orsat must have at least 0.1 percent subdivisions.

3. *Dry Molecular Weight Determination*

Any of the three sampling and analytical procedures described below may be used for determining the dry molecular weight.

3.1 Single-Point, Grab Sampling and Analytical Procedure.

3.1.1 The sampling point in the duct shall either be at the centroid of the cross section or at a point no closer to the walls than 1.00 m (3.3 ft), unless otherwise specified by the Administrator.

3.1.2 Set up the equipment as shown in Figure 3-1, making sure all connections ahead of the analyzer are tight and leak-free. If an Orsat analyzer is used, it is recommended that the analyzer be leaked-checked by following the procedure in Section 5; however, the leak-check is optional.

3.1.3 Place the probe in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Draw a sample into the analyzer and immediately analyze it for percent CO_2 and percent O_2. Determine the percentage of the gas that is N_2 and CO by subtracting the sum of the percent CO_2 and percent O_2 from 100 percent. Calculate the dry molecular weight as indicated in Section 6.3.

3.1.4 Repeat the sampling, analysis, and calculation procedures, until the dry molecular weights of any three grab samples differ from their mean by no more than 0.3 g/g-mole (0.3 lb/lb-mole). Average these three molecular weights, and report the results to the nearest 0.1 g/g-mole (lb/lb-mole).

3.2 Single-Point, Integrated Sampling and Analytical Procedure.

3.2.1 The sampling point in the duct shall be located as specified in Section 3.1.1.

3.2.2 Leak-check (optional) the flexible bag as in Section 2.2.6. Set up the equipment as shown in Figure 3-2. Just prior to sampling, leak-check (optional) the train by placing a vacuum gauge at the condenser inlet, pulling a vacuum of at least 250 mm Hg (10 in. Hg), plugging the outlet at the quick disconnect, and then turning off the pump. The vacuum should remain stable for at least 0.5 minute. Evacuate the flexible bag. Connect the probe and place it in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Next, connect the bag and make sure that all connections are tight and leak free.

3.2.3 Sample at a constant rate. The sampling run should be simultaneous with, and for the same total length of time as, the pollutant emission rate determination. Collection of at least 30 liters (1.00 ft^3) of sample gas is recommended; however, smaller volumes may be collected, if desired.

3.2.4 Obtain one integrated flue gas sample during each pollutant emission rate determination. Within 8 hours after the sample is taken, analyze it for percent CO_2 and percent O_2 using either an Orsat analyzer or a Fyrite-type combustion gas analyzer. If an Orsat analyzer is used, it is recommended that the Orsat leak-check described in Section 5 be performed before this determination; however, the check is optional. Determine the percentage of the gas that is N_2 and CO by subtracting the sum of the percent CO_2 and percent O_2 from 100 percent. Calculate the dry molecular weight as indicated in Section 6.3.

3.2.5 Repeat the analysis and calculation procedures until the individual dry molecular weights for any three analyses differ from their mean by no more than 0.3 g/g-mole (0.3 lb/lb-mole). Average these three molecular weights, and report the results to the nearest 0.1 g/g-mole (0.1 lb/lb-mole).

3.3 Multi-Point, Integrated Sampling and Analytical Procedure.

3.3.1 Unless otherwise specified by the Administrator, a minimum of eight traverse points shall be used for circular stacks having diameters less than 0.61 m (24 in.), a minimum of nine shall be used for rectangular stacks having equivalent diameters less than 0.61 m (24 in.), and a minimum of twelve traverse points shall be used for all other cases. The traverse points shall be located according to Method 1. The use of fewer points is subject to approval of the Administrator.

3.3.2 Follow the procedures outlined in Sections 3.2.2 through 3.2.5, except for the following: traverse all sampling points and sample at each point for an equal length of time. Record sampling data as shown in Figure 3-3.

4. *Emission Rate Correction Factor or Excess Air Determination*

NOTE.—A Fyrite-type combustion gas analyzer is not acceptable for excess air or emission rate correction factor determination, unless approved by the Administrator. If both percent CO_2 and percent O_2 are measured, the analytical results of any of the three procedures given below may also be used for calculating the dry molecular weight.

Each of the three procedures below shall be used only when specified in an applicable subpart of the standards. The use of these procedures for other purposes must have specific prior approval of the Administrator.

4.1 Single-Point, Grab Sampling and Analytical Procedure.

4.1.1 The sampling point in the duct shall either be at the centroid of the cross-section or at a point no closer to the walls than 1.00 m (3.3 ft), unless otherwise specified by the Administrator.

4.1.2 Set up the equipment as shown in Figure 3-1, making sure all connections ahead of the analyzer are tight and leak-free. Leak-check the Orsat analyzer according to the procedure described in Section 5. This leak-check is mandatory.

TIME	TRAVERSE PT.	Q lpm	% DEV.[a]
	AVERAGE		

$$^{a}\% \text{ DEV} = \left(\frac{Q - Q_{avg}}{Q_{avg}}\right) 100 \qquad \text{(MUST BE} < 10\%\text{)}$$

Figure 3-3. Sampling rate data.

4.1.3 Place the probe in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Draw a sample into the analyzer. For emission rate correction factor determination, immediately analyze the sample, as outlined in Sections 4.1.4 and 4.1.5, for percent CO_2 or percent O_2. If excess air is desired, proceed as follows: (1) immediately analyze the sample, as in Sections 4.1.4 and 4.1.5, for percent CO_2, O_2, and CO; (2) determine the percentage of the gas that is N_2 by subtracting the sum of the percent CO_2, percent O_2, and percent CO from 100 percent; and (3) calculate percent excess air as outlined in Section 6.2.

4.1.4 To ensure complete absorption of the CO_2, O_2, or if applicable, CO, make repeated passes through each absorbing solution until two consecutive readings are the same. Several passes (three or four) should be made between readings. (If constant readings cannot be obtained after three consecutive readings, replace the absorbing solution.)

4.1.5 After the analysis is completed, leak-check (mandatory) the Orsat analyzer once again, as described in Section 5. For the results of the analysis to be valid, the Orsat analyzer must pass this leak test before and after the analysis. NOTE.—Since this single-point, grab sampling and analytical procedure is normally conducted in conjunction with a single-point, grab sampling and analytical procedure for a pollutant, only one analysis is ordinarily conducted. Therefore, great care must be taken to obtain a valid sample and analysis. Although in most cases only CO_2 or O_2 is required, it is recommended that both CO_2 and O_2 be measured, and that Citation 5 in the Bibliography be used to validate the analytical data.

4.2 Single-Point, Integrated Sampling and Analytical Procedure.

4.2.1 The sampling point in the duct shall be located as specified in Section 4.1.1.

4.2.2 Leak-check (mandatory) the flexible bag as in Section 2.2.6. Set up the equipment as shown in Figure 3-2. Just prior to sampling, leak-check (mandatory) the train by placing a vacuum gauge at the condenser inlet, pulling a vacuum of at least 250 mm Hg (10 in. Hg), plugging the outlet at the quick disconnect, and then turning off the pump. The vacuum shall remain stable for at least 0.5 minute. Evacuate the flexible bag. Connect the probe and place it in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Next, connect the bag and make sure that all connections are tight and leak free.

4.2.3 Sample at a constant rate, or as specified by the Administrator. The sampling run must be simultaneous with, and for the same total length of time as, the pollutant emission rate determination. Collect at least 30 liters (1.00 ft^3) of sample gas. Smaller volumes may be collected, subject to approval of the Administrator.

4.2.4 Obtain one integrated flue gas sample during each pollutant emission rate determination. For emission rate correction factor determination, analyze the sample within 4 hours after it is taken for percent CO_2 or percent O_2 (as outlined in Sections 4.2.5 through 4.2.7). The Orsat analyzer must be leak-checked (see Section 5) before the analysis. If excess air is desired, proceed as follows: (1) within 4 hours after the sample is taken, analyze it (as in Sections 4.2.5 through 4.2.7) for percent CO_2, O_2, and CO; (2) determine the percentage of the gas that is N_2 by subtracting the sum of the percent CO_2, percent O_2, and percent CO from 100 percent; (3) calculate percent excess air, as outlined in Section 6.2.

4.2.5 To ensure complete absorption of the CO_2, O_2, or if applicable, CO, make repeated passes through each absorbing solution until two consecutive readings are the same. Several passes (three or four) should be made between readings. (If constant readings cannot be obtained after three consecutive readings, replace the absorbing solution.)

4.2.6 Repeat the analysis until the following criteria are met:

4.2.6.1 For percent CO_2, repeat the analytical procedure until the results of any three analyses differ by no more than (a) 0.3 percent by volume when CO_2 is greater than 4.0 percent or (b) 0.2 percent by volume when CO_2 is less than or equal to 4.0 percent. Average the three acceptable values of percent CO_2 and report the results to the nearest 0.1 percent.

4.2.6.2 For percent O_2, repeat the analytical procedure until the results of any three analyses differ by no more than (a) 0.3 percent by volume when O_2 is less than 15.0 percent or (b) 0.2 percent by volume when O_2 is greater than 15.0 percent. Average the three acceptable values of percent O_2 and report the results to the nearest 0.1 percent.

4.2.6.3 For percent CO, repeat the analytical procedure until the results of any three analyses differ by no more than 0.3 percent. Average the three acceptable values of percent CO and report the results to the nearest 0.1 percent.

4.2.7 After the analysis is completed, leak-check (mandatory) the Orsat analyzer once again, as described in Section 5. For the results of the analysis to be valid, the Orsat analyzer must pass this leak test before and after the analysis. Note: Although in most instances only CO_2 or O_2 is required, it is recommended that both CO_2 and O_2 be measured, and that Citation 5 in the Bibliography be used to validate the analytical data.

4.3 Multi-Point, Integrated Sampling and Analytical Procedure.

4.3.1 Both the minimum number of sampling points and the sampling point location shall be as specified in Section 3.3.1 of this method. The use of fewer points than specified is subject to the approval of the Administrator.

4.3.2 Follow the procedures outlined in Sections 4.2.2 through 4.2.7, except for the following: Traverse all sampling points and sample at each point for an equal length of time. Record sampling data as shown in Figure 3-3.

5. *Leak-Check Procedure for Orsat Analyzers*

Moving an Orsat analyzer frequently causes it to leak. Therefore, an Orsat analyzer should be thoroughly leak-checked on site before the flue gas sample is introduced into it. The procedure for leak-checking an Orsat analyzer is:

5.1.1 Bring the liquid level in each pipette up to the reference mark on the capillary tubing and then close the pipette stopcock.

5.1.2 Raise the leveling bulb sufficiently to bring the confining liquid meniscus onto the graduated portion of the burette and then close the manifold stopcock.

5.1.3 Record the meniscus position.

5.1.4 Observe the meniscus in the burette and the liquid level in the pipette for movement over the next 4 minutes.

5.1.5 For the Orsat analyzer to pass the leak-check, two conditions must be met.

5.1.5.1 The liquid level in each pipette must not fall below the bottom of the capillary tubing during this 4-minute interval.

5.1.5.2 The meniscus in the burette must not change by more than 0.2 ml during this 4-minute interval.

5.1.6 If the analyzer fails the leak-check procedure, all rubber connections and stopcocks should be checked until the cause of the leak is identified. Leaking stopcocks must be disassembled, cleaned, and regreased. Leaking rubber connections must be replaced. After the analyzer is reassembled, the leak-check procedure must be repeated.

6. *Calculations*

6.1 Nomenclature.

M_d = Dry molecular weight, g/g-mole (lb/lb-mole).
%EA = Percent excess air.
$\%CO_2$ = Percent CO_2 by volume (dry basis).
$\%O_2$ = Percent O_2 by volume (dry basis).
%CO = Percent CO by volume (dry basis).
$\%N_2$ = Percent N_2 by volume (dry basis).
0.264 = Ratio of O_2 to N_2 in air, v/v.
0.280 = Molecular weight of N_2 or CO, divided by 100.
0.320 = Molecular weight of O_2 divided by 100.
0.440 = Molecular weight of CO_2 divided by 100.

6.2 Percent Excess Air. Calculate the percent excess air (if applicable), by substituting the appropriate values of percent O_2, CO, and N_2 (obtained from Section 4.1.3 or 4.2.4) into Equation 3-1.

$$\%EA = \left[\frac{\%O_2 - 0.5\%CO}{0.264\,\%N_2(\%O_2 - 0.5\,\%CO)}\right]100$$

Equation 3-1

NOTE.—The equation above assumes that ambient air is used as the source of O_2 and that the fuel does not contain appreciable amounts of N_2 (as do coke oven or blast furnace gases). For those cases when appreciable amounts of N_2 are present (coal, oil, and natural gas do not contain appreciable amounts of N_2) or when oxygen enrichment is used, alternate methods, subject to approval of the Administrator, are required.

6.3 Dry Molecular Weight. Use Equation 3-2 to calculate the dry molecular weight of the stack gas

$$M_d = 0.440(\%CO_2) + 0.320(\%O_2) + 0.280(\%N_2 + \%CO)$$

Equation 3-2

NOTE.—The above equation does not consider argon in air (about 0.9 percent, molecular weight of 37.7). A negative error of about 0.4 percent is introduced. The tester may opt to include argon in the analysis using procedures subject to approval of the Administrator.

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METHOD 4—DETERMINATION OF MOISTURE CONTENT IN STACK GASES

1. *Principle and Applicability*

1.1 Principle. A gas sample is extracted at a constant rate from the source; moisture is removed from the sample stream and determined either volumetrically or gravimetrically.

1.2 Applicability. This method is applicable for determining the moisture content of stack gas.

Two procedures are given. The first is a reference method, for accurate determinations of moisture content (such as are needed to calculate emission data). The second is an approximation method, which provides estimates of percent moisture to aid in setting isokinetic sampling rates prior to a pollutant emission measurement run. The approximation method described herein is only a suggested approach; alternative means for approximating the moisture content, e.g., drying tubes, wet bulb-dry bulb techniques, condensation techniques, stoichiometric calculations, previous experience, etc., are also acceptable.

The reference method is often conducted simultaneously with a pollutant emission measurement run; when it is, calculation of percent isokinetic, pollutant emission rate, etc., for the run shall be based upon the results of the reference method or its equivalent; these calculations shall not be based upon the results of the approximation method, unless the approximation method is shown, to the satisfaction of the Administrator, U.S. Environmental Protection Agency, to be capable of yielding results within 1 percent H_2O of the reference method.

NOTE.—The reference method may yield questionable results when applied to saturated gas streams or to streams that contain water droplets. Therefore, when these conditions exist or are suspected, a second determination of the moisture content shall be made simultaneously with the reference method, as follows: Assume that the gas stream is saturated. Attach a temperature sensor [capable of measuring to ±1° C (2° F)] to the reference method probe. Measure the stack gas temperature at each traverse point (see Section 2.2.1) during the reference method traverse; calculate the average stack gas temperature. Next, determine the moisture percentage, either by: (1) using a psychrometric chart and making appropriate corrections if stack pressure is different from that of the chart, or (2) using saturation vapor pressure tables. In cases where the psychrometric chart or the saturation vapor pressure tables are not applicable (based on evaluation of the process), alternate methods, subject to the approval of the Administrator, shall be used.

2. *Reference Method*

The procedure described in Method 5 for determining moisture content is acceptable as a reference method.

2.1 Apparatus. A schematic of the sampling train used in this reference method is shown in Figure 4-1. All components shall be maintained and calibrated according to the procedure outlined in Method 5.

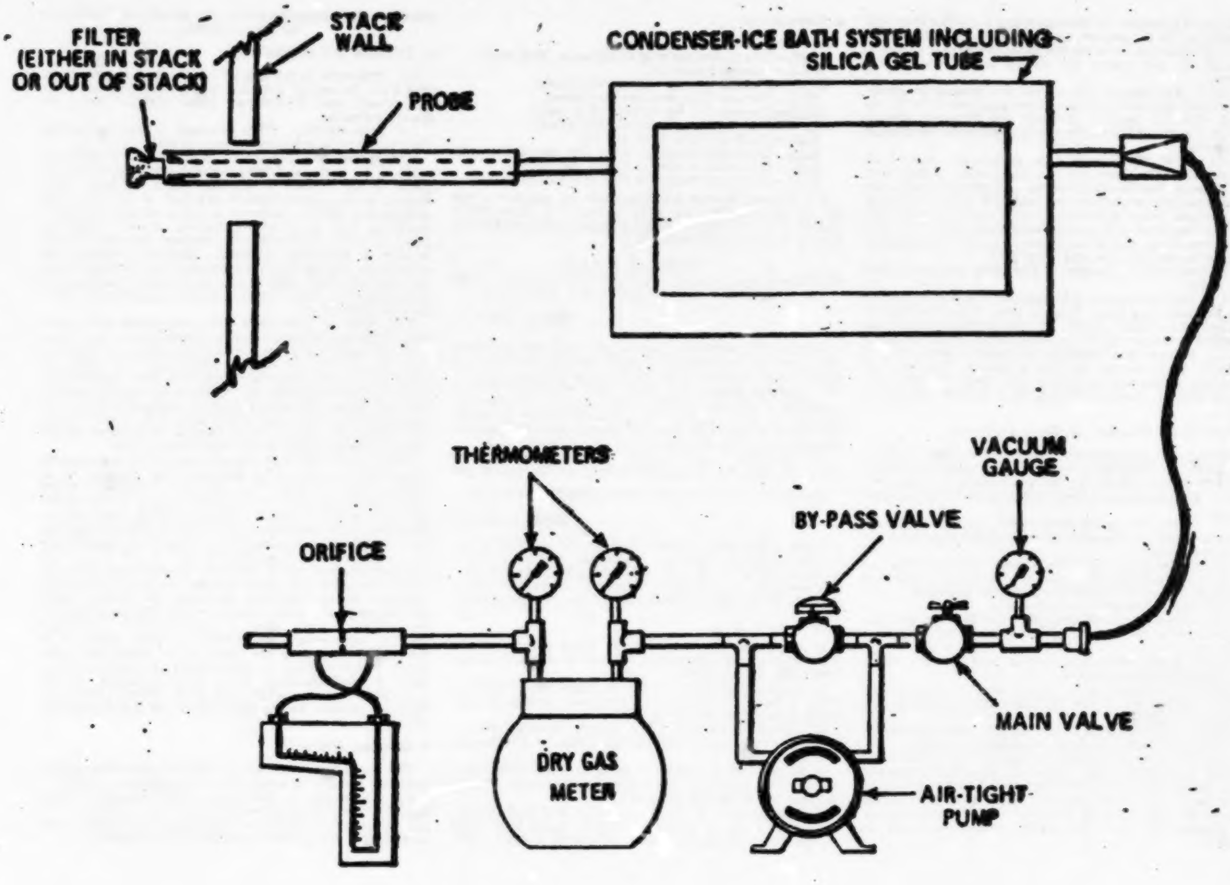

Figure 4-1. Moisture sampling train-reference method.

2.1.1 Probe. The probe is constructed of stainless steel or glass tubing, sufficiently heated to prevent water condensation, and is equipped with a filter, either in-stack (e.g., a plug of glass wool inserted into the end of the probe) or heated out-stack (e.g., as described in Method 5), to remove particulate matter.

When stack conditions permit, other metals or plastic tubing may be used for the probe, subject to the approval of the Administrator.

2.1.2 Condenser. The condenser consists of four impingers connected in series with ground glass, leak-free fittings or any similarly leak-free non-contaminating fittings. The first, third, and fourth impingers shall be of the Greenburg-Smith design, modified by replacing the tip with a 1.3 centimeter (½ inch) ID glass tube extending to about 1.3 cm (½ in.) from the bottom of the flask. The second impinger shall be of the Greenburg-Smith design with the standard tip. Modifications (e.g., using flexible connections between the impingers, using materials other than glass, or using flexible vacuum lines to connect the filter holder to the condenser) may be used, subject to the approval of the Administrator.

The first two impingers shall contain known volumes of water, the third shall be empty, and the fourth shall contain a known weight of 6- to 16-mesh indicating type silica gel, or equivalent desiccant. If the silica gel has been previously used, dry at 175° C (350° F) for 2 hours. New silica gel may be used as received. A thermometer, capable of measuring temperature to within 1° C (2° F), shall be placed at the outlet of the fourth impinger, for monitoring purposes.

Alternatively, any system may be used (subject to the approval of the Administrator) that cools the sample gas stream and allows measurement of both the water that has been condensed and the moisture leaving the condenser, each to within 1 ml or 1 g. Acceptable means are to measure the condensed water, either gravimetrically or volumetrically, and to measure the moisture leaving the condenser by: (1) monitoring the temperature and pressure at the exit of the condenser and using Dalton's law of partial pressures, or (2) passing the sample gas stream through a tared silica gel (or equivalent desiccant) trap, with exit gases kept below 20° C (68° F), and determining the weight gain.

If means other than silica gel are used to determine the amount of moisture leaving the condenser, it is recommended that silica gel (or equivalent) still be used between the condenser system and pump, to prevent moisture condensation in the pump and metering devices and to avoid the need to make corrections for moisture in the metered volume.

2.1.3 Cooling System. An ice bath container and crushed ice (or equivalent) are used to aid in condensing moisture.

2.1.4 Metering System. This system includes a vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 3° C (5.4° F), dry gas meter capable of measuring volume to within 2 percent, and related equipment as shown in Figure 4-1. Other metering systems, capable of maintaining a constant sampling rate and determining sample gas volume, may be used, subject to the approval of the Administrator.

2.1.5 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg) may be used. In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and the sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice versa for elevation decrease.

2.1.6 Graduated Cylinder and/or Balance. These items are used to measure condensed water and moisture caught in the silica gel to within 1 ml or 0.5 g. Graduated cylinders shall have subdivisions no greater than 2 ml. Most laboratory balances are capable of weighing to the nearest 0.5 g or less. These balances are suitable for use here.

2.2 Procedure. The following procedure is written for a condenser system (such as the impinger system described in Section 2.1.2) incorporating volumetric analysis to measure the condensed moisture, and silica gel and gravimetric analysis to measure the moisture leaving the condenser.

2.2.1 Unless otherwise specified by the Administrator, a minimum of eight traverse points shall be used for circular stacks having diameters less than 0.61 m (24 in.), a minimum of nine points shall be used for rectangular stacks having equivalent diameters less than 0.61 m (24 in.), and a minimum of twelve travers points shall be used in all other cases. The traverse points shall be located according to Method 1. The use of fewer points is subject to the approval of the Administrator. Select a suitable probe and probe length such that all traverse points can be sampled. Consider sampling from opposite sides of the stack (four total sampling ports) for large stacks, to permit use of shorter probe lengths. Mark the probe with heat resistant tape or by some other method to denote the proper distance into the stack or duct for each sampling point. Place known volumes of water in the first two impingers. Weigh and record the weight of the silica gel to the nearest 0.5 g, and transfer the silica gel to the fourth impinger; alternatively, the silica gel may first be transferred to the impinger, and the weight of the silica gel plus impinger recorded.

2.2.2 Select a total sampling time such that a minimum total gas volume of 0.60 scm (21 scf) will be collected, at a rate no greater than 0.021 m³/min (0.75 cfm). When both moisture content and pollutant emission rate are to be determined, the moisture determination shall be simultaneous with, and for the same total length of time as, the pollutant emission rate run, unless otherwise specified in an applicable subpart of the standards.

2.2.3 Set up the sampling train as shown in Figure 4-1. Turn on the probe heater and (if applicable) the filter heating system to temperatures of about 120° C (248° F), to prevent water condensation ahead of the condenser; allow time for the temperatures to stabilize. Place crushed ice in the ice bath container. It is recommended, but not required, that a leak check be done, as follows: Disconnect the probe from the first impinger or

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(if applicable) from the filter holder. Plug the inlet to the first impinger (or filter holder) and pull a 380 mm (15 in.) Hg vacuum; a lower vacuum may be used, provided that it is not exceeded during the test. A leakage rate in excess of 4 percent of the average sampling rate or 0.00057 m³/min (0.02 cfm), whichever is less, is unacceptable. Following the leak check, reconnect the probe to the sampling train.

2.2.4 During the sampling run, maintain a sampling rate within 10 percent of constant rate, or as specified by the Administrator. For each run, record the data required on the example data sheet shown in Figure 4-2. Be sure to record the dry gas meter reading at the beginning and end of each sampling time increment and whenever sampling is halted. Take other appropriate readings at each sample point, at least once during each time increment.

2.2.5 To begin sampling, position the probe tip at the first traverse point. Immediately start the pump and adjust the flow to the desired rate. Traverse the cross section, sampling at each traverse point for an equal length of time. Add more ice and, if necessary, salt to maintain a temperature of less than 20° C (68° F) at the silica gel outlet.

2.2.6 After collecting the sample, disconnect the probe from the filter holder (or from the first impinger) and conduct a leak check (mandatory) as described in Section 2.2.2. Record the leak rate. If the leakage rate exceeds the allowable rate, the tester shall either reject the test results or shall correct the sample volume as in Section 6.3 of Method 5. Next, measure the volume of the moisture condensed to the nearest ml. Determine the increase in weight of the silica gel (or silica gel plus impinger) to the nearest 0.5 g. Record this information (see example data sheet, Figure 4-3) and calculate the moisture percentage, as described in 2.3 below.

2.3 Calculations. Carry out the following calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation.

PLANT____________________
LOCATION____________________
OPERATOR____________________
DATE____________________
RUN NO.____________________
AMBIENT TEMPERATURE____________________
BAROMETRIC PRESSURE____________________
PROBE LENGTH m(ft)____________________

SCHEMATIC OF STACK CROSS SECTION

TRAVERSE POINT NUMBER	SAMPLING TIME (θ), min.	STACK TEMPERATURE °C (°F)	PRESSURE DIFFERENTIAL ACROSS ORIFICE METER (ΔH), mm(in.) H_2O	METER READING GAS SAMPLE VOLUME m^3 (ft^3)	ΔV_m m^3 (ft^3)	GAS SAMPLE TEMPERATURE AT DRY GAS METER		TEMPERATURE OF GAS LEAVING CONDENSER OR LAST IMPINGER, °C (°F)
						INLET ($T_{m_{in}}$), °C (°F)	OUTLET ($T_{m_{out}}$), °C (°F)	
TOTAL						Avg.	Avg.	
AVERAGE						Avg.		

Figure 4-2. Field moisture determination-reference method.

	IMPINGER VOLUME, ml	SILICA GEL WEIGHT, g
FINAL		
INITIAL		
DIFFERENCE		

Figure 4-2. Analytical data - reference method.

2.3.1 Nomenclature.

B_{ws} = Proportion of water vapor, by volume, in the gas stream.

M_w = Molecular weight of water, 18.0 g/g-mole (18.0 lb/lb-mole).

P_m = Absolute pressure (for this method, same as barometric pressure) at the dry gas meter, mm Hg (in. Hg).

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

R = Ideal gas constant, 0.06236 (mm Hg) (m³)/(g-mole) (°K) for metric units and 21.85 (in. Hg) (ft³)/(lb-mole) (°R) for English units.

T_m = Absolute temperature at meter, °K (°R).

T_{std} = Standard absolute temperature, 293° K (528° R).

V_m = Dry gas volume measured by dry gas meter, dcm (dcf).

ΔV_m = Incremental dry gas volume measured by dry gas meter at each traverse point, dcm (dcf).

$V_{m(std)}$ = Dry gas volume measured by the dry gas meter, corrected to standard conditions, dscm (dscf).

$V_{wc(std)}$ = Volume of water vapor condensed corrected to standard conditions, scm (scf).

$V_{wsg(std)}$ = Volume of water vapor collected in silica gel corrected to standard conditions, scm (scf).

V_f = Final volume of condenser water, ml.

V_i = Initial volume, if any, of condenser water, ml.

W_f = Final weight of silica gel or silica gel plus impinger, g.

W_i = Initial weight of silica gel or silica gel plus impinger, g.

Y = Dry gas meter calibration factor.

ρ_w = Density of water, 0.9982 g/ml (0.002201 lb/ml).

2.3.2 Volume of water vapor condensed.

$$V_{wc(std)}=\frac{(V_f-V_i)\rho_w R T_{std}}{P_{std}M_w}$$
$$=K_1(V_f-V_i)$$

Equation 4-1

where:

K_1=0.001333 m³/ml for metric units
=0.04707 ft³/ml for English units

2.3.3 Volume of water vapor collected in silica gel.

$$V_{wsg(std)}=\frac{(W_f-W_i)RT_{std}}{P_{std}M_w}$$
$$=K_2(W_f-W_i)$$

Equation 4-2

where:

K_2=0.001335 m³/g for metric units
=0.04715 ft³/g for English units

2.3.4 Sample gas volume.

$$V_{m(std)}=V_mY\frac{(P_m)(T_{std})}{(P_{std})(T_m)}$$
$$=K_3Y\frac{V_mP_m}{T_m}$$

Equation 4-3

where:

K_3=0.3858 °K/mm Hg for metric units
=17.64 °R/in. Hg for English units

NOTE.—If the post-test leak rate (Section 2.2.6) exceeds the allowable rate, correct the value of V_m in Equation 4-3, as described in Section 6.3 of Method 5.

2.3.5 Moisture Content.

$$B_{ws}=\frac{V_{wc(std)}+V_{wsg(std)}}{V_{wc(std)}+V_{wsg(std)}+V_{m(std)}}$$

Equation 4-4

NOTE.—In saturated or moisture droplet-laden gas streams, two calculations of the moisture content of the stack gas shall be made, one using a value based upon the saturated conditions (see Section 1.2), and another based upon the results of the impinger analysis. The lower of these two values of B_{ws} shall be considered correct.

2.3.6 Verification of constant sampling rate. For each time increment, determine the ΔV_m. Calculate the average. If the value for any time increment differs from the average by more than 10 percent, reject the results and repeat the run.

3. *Approximation Method*

The approximation method described below is presented only as a suggested method (see Section 1.2).

3.1 Apparatus.

3.1.1 Probe. Stainless steel or glass tubing, sufficiently heated to prevent water condensation and equipped with a filter (either in-stack or heated out-stack) to remove particulate matter. A plug of glass wool, inserted into the end of the probe, is a satisfactory filter.

3.1.2 Impingers. Two midget impingers, each with 30 ml capacity, or equivalent.

3.1.3 Ice Bath. Container and ice, to aid in condensing moisture in impingers.

3.1.4 Drying Tube. Tube packed with new or regenerated 6- to 16-mesh indicating-type silica gel (or equivalent desiccant), to dry the sample gas and to protect the meter and pump.

3.1.5 Valve. Needle valve, to regulate the sample gas flow rate.

3.1.6 Pump. Leak-free, diaphragm type, or equivalent, to pull the gas sample through the train.

3.1.7 Volume meter. Dry gas meter, sufficiently accurate to measure the sample volume within 2%, and calibrated over the range of flow rates and conditions actually encountered during sampling.

3.1.8 Rate Meter. Rotameter, to measure the flow range from 0 to 3 lpm (0 to 0.11 cfm).

3.1.9 Graduated Cylinder. 25 ml.

3.1.10 Barometer. Mercury, aneroid, or other barometer, as described in Section 2.1.5 above.

3.1.11 Vacuum Gauge. At least 760 mm Hg (30 in. Hg) gauge, to be used for the sampling leak check.

3.2 Procedure.

3.2.1 Place exactly 5 ml distilled water in each impinger. Assemble the apparatus without the probe as shown in Figure 4-4. Leak check the train by placing a vacuum gauge at the inlet to the first impinger and drawing a vacuum of at least 250 mm Hg (10 in. Hg), plugging the outlet of the rotameter, and then turning off the pump. The vacuum shall remain constant for at least one minute. Carefully release the vacuum gauge before unplugging the rotameter end.

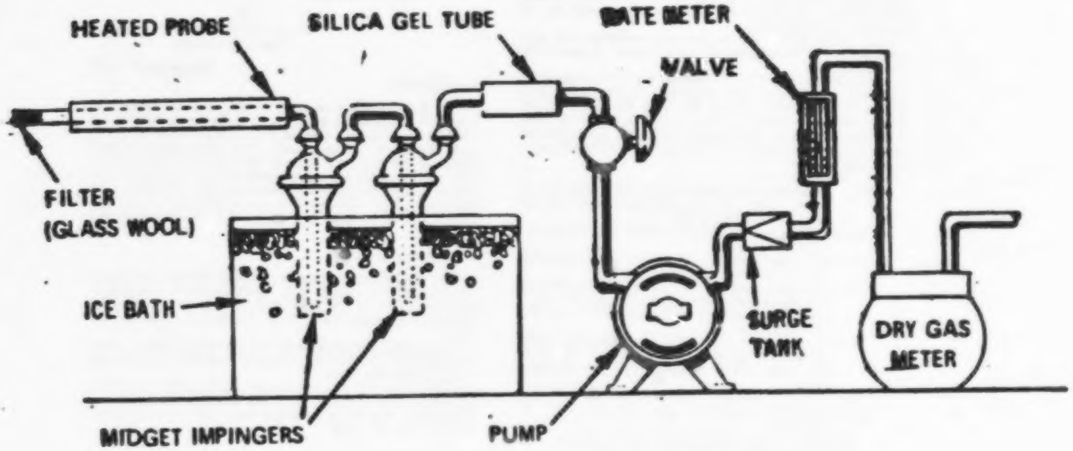
HEATED PROBE
SILICA GEL TUBE
RATE METER
VALVE
FILTER (GLASS WOOL)
ICE BATH
SURGE TANK
DRY GAS METER
MIDGET IMPINGERS
PUMP

Figure 4-4. Moisture sampling train - approximation method.

LOCATION______________________________ COMMENTS

TEST__________________________________

DATE__________________________________

OPERATOR______________________________

BAROMETRIC PRESSURE____________________

CLOCK TIME	GAS VOLUME THROUGH METER, (Vm), m^3 (ft^3)	RATE METER SETTING m^3/min. (ft^3/min.)	METER TEMPERATURE, °C (°F)

Figure 4-5. Field moisture determination - approximation method.

3.2.2 Connect the probe, insert it into the stack, and sample at a constant rate of 2 lpm (0.071 cfm). Continue sampling until the dry gas meter registers about 30 liters (1.1 ft³) or until visible liquid droplets are carried over from the first impinger to the second. Record temperature, pressure, and dry gas meter readings as required by Figure 4-2.

3.2.3 After collecting the sample, combine the contents of the two impingers and measure the volume to the nearest 0.5 ml.

3.3 Calculations. The calculation method presented is designed to estimate the moisture in the stack gas; therefore, other data, which are only necessary for accurate moisture determinations, are not collected. The following equations adequately estimate the moisture content, for the purpose of determining isokinetic sampling rate settings.

3.3.1 Nomenclature.

B_{wm} = Approximate proportion, by volume, of water vapor in the gas stream leaving the second impinger, 0.025.

B_{ws} = Water vapor in the gas stream, proportion by volume.

M_w = Molecular weight of water, 18.0 g/g-mole (18.0 lb/lb-mole)

P_m = Absolute pressure (for this method, same as barometric pressure) at the dry gas meter.

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

R = Ideal gas constant, 0.06236 (mm Hg) (m³)/(g-mole) (°K) for metric units and 21.85 (in. Hg) (ft³)/lb-mole) (°R) for English units.

T_m = Absolute temperature at meter, °K (°R)

T_{std} = Standard absolute temperature, 293° K (528° R)

V_f = Final volume of impinger contents, ml.

V_i = Initial volume of impinger contents, ml.

V_m = Dry gas volume measured by dry gas meter, dcm (dcf).

$V_{m(std)}$ = Dry gas volume measured by dry gas meter, corrected to standard conditions, dscm (dscf).

$V_{wc(std)}$ = Volume of water vapor condensed, corrected to standard conditions, scm (scf).

ρ_w = Density of water, 0.9982 g/ml (0.002201 lb/ml).

3.3.2 Volume of water vapor collected.

$$V_{wc} = \frac{(V_f - V_i)\rho_w R T_{std}}{P_{std} M_w}$$

$$= K_1 (V_f - V_i)$$

Equation 4-5

where:
K_1 = 0.001333 m³/ml for metric units
= 0.04707 ft³/ml for English units.

3.3.3 Gas volume.

$$V_{m(std)} = V_m \left(\frac{P_m}{P_{std}}\right)\left(\frac{T_{std}}{T_m}\right)$$

$$= K_2 \frac{V_m P_m}{T_m}$$

Equation 4-6

where:
K_2 = 0.3858 °K/mm Hg for metric units
= 17.64 °R/in. Hg for English units

3.3.4 Approximate moisture content.

$$B_{ws} = \frac{V_{wc}}{V_{wc} + V_{m(std)}} + B_{wm}$$

$$= \frac{V_{wc}}{V_{wc} + V_{m(std)}} + (0.025)$$

Equation 4-7

4. Calibration

4.1 For the reference method, calibrate equipment as specified in the following sections of Method 5: Section 5.3 (metering system); Section 5.5 (temperature gauges); and Section 5.7 (barometer). The recommended leak check of the metering system (Section 5.6 of Method 5) also applies to the reference method. For the approximation method, use the procedures outlined in Section 5.1.1 of Method 6 to calibrate the metering system, and the procedure of Method 5, Section 5.7 to calibrate the barometer.

5. Bibliography

1. Air Pollution Engineering Manual (Second Edition). Danielson, J. A. (ed.). U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, N.C. Publication No. AP-40. 1973.

2. Devorkin, Howard, et al. Air Pollution Source Testing Manual. Air Pollution Control District, Los Angeles, Calif. November, 1963.

3. Methods for Determination of Velocity, Volume, Dust and Mist Content of Gases. Western Precipitation Division of Joy Manufacturing Co., Los Angeles, Calif. Bulletin WP-50. 1968.

METHOD 5—DETERMINATION OF PARTICULATE EMISSIONS FROM STATIONARY SOURCES

1. Principle and Applicability

1.1 Principle. Particulate matter is withdrawn isokinetically from the source and collected on a glass fiber filter maintained at a temperature in the range of 120±14° C (248±25° F) or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator, U.S. Environmental Protection Agency, for a particular application. The particulate mass, which includes any material that condenses at or above the filtration temperature, is determined gravimetrically after removal of uncombined water.

1.2 Applicability. This method is applicable for the determination of particulate emissions from stationary sources.

2. Apparatus

2.1 Sampling Train. A schematic of the sampling train used in this method is shown in Figure 5-1. Complete construction details are given in APTD-0581 (Citation 2 in Section 7); commercial models of this train are also available. For changes from APTD-0581 and for allowable modifications of the train shown in Figure 5-1, see the following subsections.

The operating and maintenance procedures for the sampling train are described in APTD-0576 (Citation 3 in Section 7). Since correct usage is important in obtaining valid results, all users should read APTD-0576 and adopt the operating and maintenance procedures outlined in it, unless otherwise specified herein. The sampling train consists of the following components:

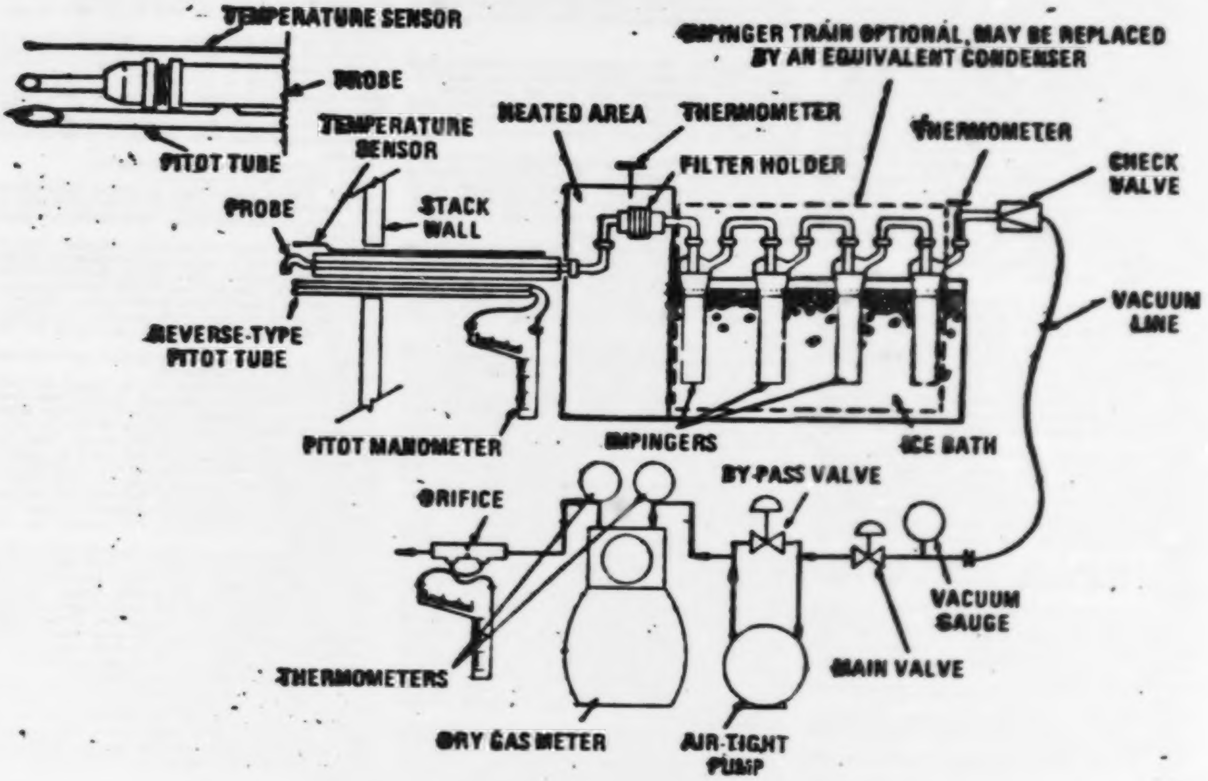

Figure 5 1. *Particulate-sampling train.*

2.1.1 Probe Nozzle. Stainless steel (316) or glass with sharp, tapered leading edge. The angle of taper shall be ≤30° and the taper shall be on the outside to preserve a constant internal diameter. The probe nozzle shall be of the button-hook or elbow design, unless otherwise specified by the Administrator. If made of stainless steel, the nozzle shall be constructed from seamless tubing; other materials of construction may be used, subject to the approval of the Administrator.

A range of nozzle sizes suitable for isokinetic sampling should be available, e.g., 0.32 to 1.27 cm (⅛ to ½ in.)—or larger if higher volume sampling trains are used—inside diameter (ID) nozzles in increments of 0.16 cm (1/16 in.). Each nozzle shall be calibrated according to the procedures outlined in Section 5.

2.1.2 Probe Liner. Borosilicate or quartz glass tubing with a heating system capable of maintaining a gas temperature at the exit end during sampling of 120±14° C (248±25° F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator for a particular application. (The tester may opt to operate the equipment at a temperature lower than that specified.) Since the actual temperature at the outlet of the probe is not usually monitored during sampling, probes constructed according to APTD-0581 and utilizing the calibration curves of APTD-0576 (or calibrated according to the procedure outlined in APTD-0576) will be considered acceptable.

Either borosilicate or quartz glass probe liners may be used for stack temperatures up to about 480° C (900° F); quartz liners shall be used for temperatures between 480 and 900° C (900 and 1,650° F). Both types of liners may be used at higher temperatures than specified for short periods of time, subject to the approval of the Administrator. The softening temperature for borosilicate is 820° C (1,508° F), and for quartz it is 1,500° C (2,732° F).

Whenever practical, every effort should be made to use borosilicate or quartz glass probe liners. Alternatively, metal liners (e.g., 316 stainless steel, Incoloy 825,[1] or other corrosion resistant metals) made of seamless tubing may be used, subject to the approval of the Administrator.

2.1.3 Pitot Tube. Type S, as described in Section 2.1 of Method 2, or other device approved by the Administrator. The pitot tube shall be attached to the probe (as shown in Figure 5-1) to allow constant monitoring of the stack gas velocity. The impact (high pressure) opening plane of the pitot tube shall be even with or above the nozzle entry plane (see Method 2, Figure 2-6b) during sampling. The Type S pitot tube assembly shall have a known coefficient, determined as outlined in Section 4 of Method 2.

2.1.4 Differential Pressure Gauge. Inclined manometer or equivalent device (two), as described in Section 2.2 of Method 2. One manometer shall be used for velocity head (Δp) readings, and the other, for orifice differential pressure readings.

2.1.5 Filter Holder. Borosilicate glass, with a glass frit filter support and a silicone rubber gasket. Other materials of construction (e.g., stainless steel, Teflon, Viton) may be used, subject to approval of the Administrator. The holder design shall provide a positive seal against leakage from the outside or around the filter. The holder shall be attached immediately at the outlet of the probe (or cyclone, if used).

2.1.6 Filter Heating System. Any heating system capable of maintaining a temperature around the filter holder during sampling of 120±14° C (248±25° F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator for a particular application. Alternatively, the tester may opt to operate the equipment at a temperature lower than that specified. A temperature gauge capable of measuring temperature to within 3° C (5.4° F) shall be installed so that the temperature around the filter holder can be regulated and monitored during sampling. Heating systems other than the one shown in APTD-0581 may be used.

2.1.7 Condenser. The following system shall be used to determine the stack gas moisture content: Four impingers connected in series with leak-free ground glass fittings or any similar leak-free non-contaminating fittings. The first, third, and fourth impingers shall be of the Greenburg-Smith design, modified by replacing the tip with 1.3 cm (½ in.) ID glass tube extending to about 1.3 cm (½ in.) from the bottom of the flask. The second impinger shall be of the Greenburg-Smith design with the standard tip. Modifications (e.g., using flexible connections between the impingers, using materials other than glass, or using flexible vacuum lines to connect the filter holder to the condenser) may be used, subject to the approval of the Administrator. The first and second impingers shall contain known quantities of water (Section 4.1.3), the third shall be empty, and the fourth shall contain a known weight of silica gel, or equivalent desiccant. A thermometer, capable of measuring temperature to within 1° C (2° F) shall be placed at the outlet of the fourth impinger for monitoring purposes.

Alternatively, any system that cools the sample gas stream and allows measurement of the water condensed and moisture leaving the condenser, each to within 1 ml or 1 g may be used, subject to the approval of the Administrator. Acceptable means are to measure the condensed water either gravimetrically or volumetrically and to measure the moisture leaving the condenser by: (1) monitoring the temperature and pressure at the exit of the condenser and using Dalton's law of partial pressures; or (2) passing the sample gas stream through a tared silica gel (or equivalent desiccant) trap with exit gases kept below 20° C (68° F) and determining the weight gain.

If means other than silica gel are used to determine the amount of moisture leaving the condenser, it is recommended that silica gel (or equivalent) still be used between the condenser system and pump to prevent moisture condensation in the pump and metering devices and to avoid the need to make corrections for moisture in the metered volume.

NOTE.—If a determination of the particulate matter collected in the impingers is desired in addition to moisture content, the impinger system described above shall be used, without modification. Individual States or control agencies requiring this information shall be contacted as to the sample recovery and analysis of the impinger contents.

2.1.8 Metering System. Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 3° C (5.4° F), dry gas meter capable of measuring volume to within 2 percent, and related equipment, as shown in Figure 5-1. Other metering systems capable of maintaining sampling rates within 10 percent of isokinetic and of determining sample volumes to within 2 percent may be used, subject to the approval of the Administrator. When the metering system is used in conjunction with a pitot tube, the system shall enable checks of isokinetic rates.

Sampling trains utilizing metering systems designed for higher flow rates than that described in APTD-0581 or APTD-0576 may be used provided that the specifications of this method are met.

2.1.9 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg). In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is

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[1] Mention of trade names or specific products does not constitute endorsement by the Environmental Protection Agency.

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the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice versa for elevation decrease.

2.1.10 Gas Density Determination Equipment. Temperature sensor and pressure gauge, as described in Sections 2.3 and 2.4 of Method 2, and gas analyzer, if necessary, as described in Method 3. The temperature sensor shall, preferably, be permanently attached to the pitot tube or sampling probe in a fixed configuration, such that the tip of the sensor extends beyond the leading edge of the probe sheath and does not touch any metal. Alternatively, the sensor may be attached just prior to use in the field. Note, however, that if the temperature sensor is attached in the field, the sensor must be placed in an interference-free arrangement with respect to the Type S pitot tube openings (see Method 2, Figure 2-7). As a second alternative, if a difference of not more than 1 percent in the average velocity measurement is to be introduced, the temperature gauge need not be attached to the probe or pitot tube. (This alternative is subject to the approval of the Administrator.)

2.2 Sample Recovery. The following items are needed:

2.2.1 Probe-Liner and Probe-Nozzle Brushes. Nylon bristle brushes with stainless steel wire handles. The probe brush shall have extensions (at least as long as the probe) of stainless steel, Nylon, Teflon, or similarly inert material. The brushes shall be properly sized and shaped to brush out the probe liner and nozzle.

2.2.2 Wash Bottles—Two. Glass wash bottles are recommended; polyethylene wash bottles may be used at the option of the tester. It is recommended that acetone not be stored in polyethylene bottles for longer than a month.

2.2.3 Glass Sample Storage Containers. Chemically resistant, borosilicate glass bottles, for acetone washes, 500 ml or 1000 ml. Screw cap liners shall either be rubber-backed Teflon or shall be constructed so as to be leak-free and resistant to chemical attack by acetone. (Narrow mouth glass bottles have been found to be less prone to leakage.) Alternatively, polyethylene bottles may be used.

2.2.4 Petri Dishes. For filter samples, glass or polyethylene, unless otherwise specified by the Administrator.

2.2.5 Graduated Cylinder and/or Balance. To measure condensed water to within 1 ml or 1 g. Graduated cylinders shall have subdivisions no greater than 2 ml. Most laboratory balances are capable of weighing to the nearest 0.5 g or less. Any of these balances is suitable for use here and in Section 2.3.4.

2.2.6 Plastic Storage Containers. Air-tight containers to store silica gel.

2.2.7 Funnel and Rubber Policeman. To aid in transfer of silica gel to container; not necessary if silica gel is weighed in the field.

2.2.8 Funnel. Glass or polyethylene, to aid in sample recovery.

2.3 Analysis. For analysis, the following equipment is needed.

2.3.1 Glass Weighing Dishes.

2.3.2 Desiccator.

2.3.3 Analytical Balance. To measure to within 0.1 mg.

2.3.4 Balance. To measure to within 0.5 g.

2.3.5 Beakers. 250 ml.

2.3.6 Hygrometer. To measure the relative humidity of the laboratory environment.

2.3.7 Temperature Gauge. To measure the temperature of the laboratory environment.

3. *Reagents*

3.1 Sampling. The reagents used in sampling are as follows:

3.1.1 Filters. Glass fiber filters, without organic binder, exhibiting at least 99.95 percent efficiency (≤0.05 percent penetration) on 0.3-micron dioctyl phthalate smoke particles. The filter efficiency test shall be conducted in accordance with ASTM standard method D 2986-71. Test data from the supplier's quality control program are sufficient for this purpose.

3.1.2 Silica Gel. Indicating type, 6 to 16 mesh. If previously used, dry at 175° C (350° F) for 2 hours. New silica gel may be used as received. Alternatively, other types of desiccants (equivalent or better) may be used, subject to the approval of the Administrator.

3.1.3 Water. When analysis of the material caught in the impingers is required, distilled water shall be used. Run blanks prior to field use to eliminate a high blank on test samples.

3.1.4 Crushed Ice.

3.1.5 Stopcock Grease. Acetone-insoluble, heat-stable silicone grease. This is not necessary if screw-on connectors with Teflon sleeves, or similar, are used. Alternatively, other types of stopcock grease may be used, subject to the approval of the Administrator.

3.2 Sample Recovery. Acetone—reagent grade, ≤0.001 percent residue, in glass bottles—is required. Acetone from metal containers generally has a high residue blank and should not be used. Sometimes, suppliers transfer acetone to glass bottles from metal containers; thus, acetone blanks shall be run prior to field use and only acetone with low blank values (≤0.001 percent) shall be used. In no case shall a blank value of greater than 0.001 percent of the weight of acetone used be subtracted from the sample weight.

3.3 Analysis. Two reagents are required for the analysis:

3.3.1 Acetone. Same as 3.2.

3.3.2 Desiccant. Anhydrous calcium sulfate, indicating type. Alternatively, other types of desiccants may be used, subject to the approval of the Administrator.

4. *Procedure*

4.1 Sampling. The complexity of this method is such that, in order to obtain reliable results, testers should be trained and experienced with the test procedures.

4.1.1 Pretest Preparation. All the components shall be maintained and calibrated according to the procedure described in APTD-0576, unless otherwise specified herein.

Weigh several 200 to 300 g portions of silica gel in air-tight containers to the nearest 0.5 g. Record the total weight of the silica gel plus container, on each container. As an alternative, the silica gel need not be preweighed, but may be weighed directly in its impinger or sampling holder just prior to train assembly.

Check filters visually against light for irregularities and flaws or pinhole leaks. Label filters of the proper diameter on the back side near the edge using numbering machine ink. As an alternative, label the shipping containers (glass or plastic petri dishes) and keep the filters in these containers at all times except during sampling and weighing.

Desiccate the filters at 20±5.6° C (68±10° F) and ambient pressure for at least 24 hours and weigh at intervals of at least 6 hours to a constant weight, i.e., <0.5 mg change from previous weighing; record results to the nearest 0.1 mg. During each weighing the filter must not be exposed to the laboratory atmosphere for a period greater than 2 minutes and a relative humidity above 50 percent. Alternatively (unless otherwise specified by the Administrator), the filters may be oven dried at 105° C (220° F) for 2 to 3 hours, desiccated for 2 hours, and weighed. Procedures other than those described, which account for relative humidity effects, may be used, subject to the approval of the Administrator.

4.1.2 Preliminary Determinations. Select the sampling site and the minimum number of sampling points according to Method 1 or as specified by the Administrator. Determine the stack pressure, temperature, and the range of velocity heads using Method 2; it is recommended that a leak-check of the pitot lines (see Method 2, Section 3.1) be performed. Determine the moisture content using Approximation Method 4 or its alternatives for the purpose of making isokinetic sampling rate settings. Determine the stack gas dry molecular weight, as described in Method 2, Section 3.6; if integrated Method 3 sampling is used for molecular weight determination, the integrated bag sample shall be taken simultaneously with, and for the same total length of time as, the particulate sample run.

Select a nozzle size based on the range of velocity heads, such that it is not necessary to change the nozzle size in order to maintain isokinetic sampling rates. During the run, do not change the nozzle size. Ensure that the proper differential pressure gauge is chosen for the range of velocity heads encountered (see Section 2.2 of Method 2).

Select a suitable probe liner and probe length such that all traverse points can be sampled. For large stacks, consider sampling from opposite sides of the stack to reduce the length of probes.

Select a total sampling time greater than or equal to the minimum total sampling time specified in the test procedures for the specific industry such that (1) the sampling time per point is not less than 2 min (or some greater time interval as specified by the Administrator), and (2) the sample volume taken (corrected to standard conditions) will exceed the required minimum total gas sample volume. The latter is based on an approximate average sampling rate.

It is recommended that the number of minutes sampled at each point be an integer or an integer plus one-half minute, in order to avoid timekeeping errors.

In some circumstances, e.g., batch cycles, it may be necessary to sample for shorter times at the traverse points and to obtain smaller gas sample volumes. In these cases, the Administrator's approval must first be obtained.

4.1.3 Preparation of Collection Train. During preparation and assembly of the sampling train, keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.

Place 100 ml of water in each of the first two impingers, leave the third impinger empty, and transfer approximately 200 to 300 g of preweighed silica gel from its container to the fourth impinger. More silica gel may be used, but care should be taken to ensure that it is not entrained and carried out from the impinger during sampling. Place the container in a clean place for later use in the sample recovery. Alternatively, the weight of the silica gel plus impinger may be determined to the nearest 0.5 g and recorded.

Using a tweezer or clean disposable surgical gloves, place a labeled (identified) and weighed filter in the filter holder. Be sure that the filter is properly centered and the gasket properly placed so as to prevent the sample gas stream from circumventing the filter. Check the filter for tears after assembly is completed.

When glass liners are used, install the selected nozzle using a Viton A O-ring when stack temperatures are less than 260° C (500° F) and an asbestos string gasket when temperatures are higher. See APTD-0576 for details. Other connecting systems using either 316 stainless steel or Teflon ferrules may be used. When metal liners are used, install the nozzle as above or by a leak-free direct mechanical connection. Mark the probe with heat resistant tape or by some other method to denote the proper distance into the stack or duct for each sampling point.

Set up the train as in Figure 5-1, using (if necessary) a very light coat of silicone grease on all ground glass joints, greasing only the outer portion (see APTD-0576) to avoid possibility of contamination by the silicone grease. Subject to the approval of the Administrator, a glass cyclone may be used between the probe and filter holder when the total particulate catch is expected to exceed 100 mg or when water droplets are present in the stack gas.

Place crushed ice around the impingers.

4.1.4 Leak-Check Procedures.

4.1.4.1 Pretest Leak-Check. A pretest leak-check is recommended, but not required. If the tester opts to conduct the pretest leak-check, the following procedure shall be used.

After the sampling train has been assembled, turn on and set the filter and probe heating systems at the desired operating temperatures. Allow time for the temperatures to stabilize. If a Viton A O-ring or other leak-free connection is used in assembling the probe nozzle to the probe liner, leak-check the train at the sampling site by plugging the nozzle and pulling a 380 mm Hg (15 in. Hg) vacuum.

NOTE.—A lower vacuum may be used, provided that it is not exceeded during the test.

If an asbestos string is used, do not connect the probe to the train during the leak-check. Instead, leak-check the train by first plugging the inlet to the filter holder (cyclone, if applicable) and pulling a 380 mm Hg (15 in. Hg) vacuum (see Note immediately above). Then connect the probe to the train and leak-check at about 25 mm Hg (1 in. Hg) vacuum; alternatively, the probe may be leak-checked with the rest of the sampling train, in one step, at 380 mm Hg (15 in. Hg) vacuum. Leakage rates in excess of 4 percent of the average sampling rate or 0.00057 m³/min (0.02 cfm), whichever is less, are unacceptable.

The following leak-check instructions for the sampling train described in APTD-0576 and APTD-0581 may be helpful. Start the pump with bypass valve fully open and coarse adjust valve completely closed. Partially open the coarse adjust valve and slowly close the bypass valve until the desired vacuum is reached. Do not reverse direction of bypass valve; this will cause water to back up into the filter holder. If the desired vacuum is exceeded, either leak-check at this higher vacuum or end the leak check as shown below and start over.

When the leak-check is completed, first slowly remove the plug from the inlet to the probe, filter holder, or cyclone (if applicable) and immediately turn off the vacuum pump. This prevents the water in the impingers from being forced backward into the filter holder and silica gel from being entrained backward into the third impinger.

4.1.4.2 Leak-Checks During Sample Run. If, during the sampling run, a component (e.g., filter assembly or impinger) change becomes necessary, a leak-check shall be conducted immediately before the change is made. The leak-check shall be done according to the procedure outlined in Section 4.1.4.1 above, except that it shall be done at a vacuum equal to or greater than the maximum value recorded up to that point in the test. If the leakage rate is found to be no greater than 0.00057 m³/min (0.02 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction will need to be applied to the total volume of dry gas metered; if, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and plan to correct the sample volume as shown in Section 6.3 of this method, or shall void the sampling run.

Immediately after component changes, leak-checks are optional; if such leak-checks are done, the procedure outlined in Section 4.1.4.1 above shall be used.

4.1.4.3 Post-test Leak-Check. A leak-check is mandatory at the conclusion of each sampling run. The leak-check shall be done in accordance with the procedures outlined in Section 4.1.4.1, except that it shall be conducted at a vacuum equal to or greater than the maximum value reached during the sampling run. If the leakage rate is found to be no greater than 0.00057 m³/min (0.02 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction need be applied to the total volume of dry gas metered. If, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and correct the sample volume as shown in Section 6.3 of this method, or shall void the sampling run.

4.1.5 Particulate Train Operation. During the sampling run, maintain an isokinetic sampling rate (within 10 percent of true isokinetic unless otherwise specified by the Administrator) and a temperature around the filter of 120±14° C (248±25° F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator.

For each run, record the data required on a data sheet such as the one shown in Figure 5-2. Be sure to record the initial dry gas meter reading. Record the dry gas meter readings at the beginning and end of each sampling time increment, when changes in flow rates are made, before and after each leak check, and when sampling is halted.

Take other readings required by Figure 5-2 at least once at each sample point during each time increment and additional readings when significant changes (20 percent variation in velocity head readings) necessitate additional adjustments in flow rate. Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse.

Clean the portholes prior to the test run to minimize the chance of sampling deposited material. To begin sampling, remove the nozzle cap, verify that the filter and probe heating systems are up to temperature, and that the pitot tube and probe are properly positioned. Position the nozzle at the first traverse point with the tip pointing directly into the gas stream. Immediately start the pump and adjust the flow to isokinetic conditions. Nomographs are available, which aid in the rapid adjustment of the isokinetic sampling rate without excessive computations. These nomographs are designed for use when the Type S pitot tube coefficient is 0.85±0.02, and the stack gas equivalent density (dry molecular weight) is equal to 29±4. APTD-0576 details the procedure for using the nomographs. If C_p and M_d are outside the above stated ranges do not use the nomographs unless appropriate steps (see Citation 7 in Section 7) are taken to compensate for the deviations.

PLANT
LOCATION
OPERATOR
DATE
RUN NO.
SAMPLE BOX NO.
METER BOX NO.
METER ΔH@
C FACTOR
PITOT TUBE COEFFICIENT, C_p

SCHEMATIC OF STACK CROSS SECTION

AMBIENT TEMPERATURE
BAROMETRIC PRESSURE
ASSUMED MOISTURE, %
PROBE LENGTH, m (ft)
NOZZLE IDENTIFICATION NO.
AVERAGE CALIBRATED NOZZLE DIAMETER, cm (in.)
PROBE HEATER SETTING
LEAK RATE, m^3/min.(cfm)
PROBE LINER MATERIAL
STATIC PRESSURE, mm Hg (in. Hg)
FILTER NO.

TRAVERSE POINT NUMBER	SAMPLING TIME (θ), min.	VACUUM mm Hg (in. Hg)	STACK TEMPERATURE (T_S) °C (°F)	VELOCITY HEAD (ΔP_S), mm (in.) H_2O	PRESSURE DIFFERENTIAL ACROSS ORIFICE METER mm H_2O (in. H_2O)	GAS SAMPLE VOLUME m^3 (ft^3)	GAS SAMPLE TEMPERATURE AT DRY GAS METER		FILTER HOLDER TEMPERATURE, °C (°F)	TEMPERATURE OF GAS LEAVING CONDENSER OR LAST IMPINGER, °C (°F)
							INLET, °C (°F)	OUTLET, °C (°F)		
TOTAL							Avg.	Avg.		
AVERAGE							Avg.			

Figure 5-2. Particulate field data.

When the stack is under significant negative pressure (height of impinger stem), take care to close the coarse adjust valve before inserting the probe into the stack to prevent water from backing into the filter holder. If necessary, the pump may be turned on with the coarse adjust valve closed.

When the probe is in position, block off the openings around the probe and porthole to prevent unrepresentative dilution of the gas stream.

Traverse the stack cross-section, as required by Method 1 or as specified by the Administrator, being careful not to bump the probe nozzle into the stack walls when sampling near the walls or when removing or inserting the probe through the portholes; this minimizes the chance of extracting deposited material.

During the test run, make periodic adjustments to keep the temperature around the filter holder at the proper level; add more ice and, if necessary, salt to maintain a temperature of less than 20° C (68° F) at the condenser/silica gel outlet. Also, periodically check the level and zero of the manometer.

If the pressure drop across the filter becomes too high, making isokinetic sampling difficult to maintain, the filter may be replaced in the midst of a sample run. It is recommended that another complete filter assembly be used rather than attempting to change the filter itself. Before a new filter assembly is installed, conduct a leak-check (see Section 4.1.4.2). The total particulate weight shall include the summation of all filter assembly catches.

A single train shall be used for the entire sample run, except in cases where simultaneous sampling is required in two or more separate ducts or at two or more different locations within the same duct, or, in cases where equipment failure necessitates a change of trains. In all other situations, the use of two or more trains will be subject to the approval of the Administrator.

Note that when two or more trains are used, separate analyses of the front-half and (if applicable) impinger catches from each train shall be performed, unless identical nozzle sizes were used on all trains, in which case, the front-half catches from the individual trains may be combined (as may the impinger catches) and one analysis of front-half catch and one analysis of impinger catch may be performed. Consult with the Administrator for details concerning the calculation of results when two or more trains are used.

At the end of the sample run, turn off the coarse adjust valve, remove the probe and nozzle from the stack, turn off the pump, record the final dry gas meter reading, and conduct a post-test leak-check, as outlined in Section 4.1.4.3. Also, leak-check the pitot lines as described in Method 2, Section 3.1; the lines must pass this leak-check, in order to validate the velocity head data.

4.1.6 Calculation of Percent Isokinetic. Calculate percent isokinetic (see Calculations, Section 6) to determine whether the run was valid or another test run should be made. If there was difficulty in maintaining isokinetic rates due to source conditions, consult with the Administrator for possible variance on the isokinetic rates.

4.2 Sample Recovery. Proper cleanup procedure begins as soon as the probe is removed from the stack at the end of the sampling period. Allow the probe to cool.

When the probe can be safely handled, wipe off all external particulate matter near the tip of the probe nozzle and place a cap over it to prevent losing or gaining particulate matter. Do not cap off the probe tip tightly while the sampling train is cooling down as this would create a vacuum in the filter holder, thus drawing water from the impingers into the filter holder.

Before moving the sample train to the cleanup site, remove the probe from the sample train, wipe off the silicone grease, and cap the open outlet of the probe. Be careful not to lose any condensate that might be present. Wipe off the silicone grease from the filter inlet where the probe was fastened and cap it. Remove the umbilical cord from the last impinger and cap the impinger. If a flexible line is used between the first impinger or condenser and the filter holder, disconnect the line at the filter holder and let any condensed water or liquid drain into the impingers or condenser. After wiping off the silicone grease, cap off the filter holder outlet and impinger inlet. Either ground-glass stoppers, plastic caps, or serum caps may be used to close these openings.

Transfer the probe and filter-impinger assembly to the cleanup area. This area should be clean and protected from the wind so that the chances of contaminating or losing the sample will be minimized.

Save a portion of the acetone used for cleanup as a blank. Take 200 ml of this acetone directly from the wash bottle being used and place it in a glass sample container labeled "acetone blank."

Inspect the train prior to and during disassembly and note any abnormal conditions. Treat the samples as follows:

Container No. 1. Carefully remove the filter from the filter holder and place it in its identified petri dish container. Use a pair of tweezers and/or clean disposable surgical gloves to handle the filter. If it is necessary to fold the filter, do so such that the particulate cake is inside the fold. Carefully transfer to the petri dish any particulate matter and/or filter fibers which adhere to the filter holder gasket, by using a dry nylon bristle brush and/or a sharp-edged blade. Seal the container.

Container No. 2. Taking care to see that dust on the outside of the probe or other exterior surfaces does not get into the sample, quantitatively recover particulate matter or any condensate from the probe nozzle, probe fitting, probe liner, and front half of the filter holder by washing these components with acetone and placing the wash in a glass container. Distilled water may be used instead of acetone when approved by the Administrator and shall be used when specified by the Administrator; in these cases, save a water blank and follow the Administrator's directions on analysis. Perform the acetone rinses as follows:

Carefully remove the probe nozzle and clean the inside surface by rinsing with acetone from a wash bottle and brushing with a nylon bristle brush. Brush until the acetone rinse shows no visible particles, after which make a final rinse of the inside surface with acetone.

Brush and rinse the inside parts of the Swagelok fitting with acetone in a similar way until no visible particles remain.

Rinse the probe liner with acetone by tilting and rotating the probe while squirting acetone into its upper end so that all inside surfaces will be wetted with acetone. Let the acetone drain from the lower end into the sample container. A funnel (glass or polyethylene) may be used to aid in transferring liquid washes to the container. Follow the acetone rinse with a probe brush. Hold the probe in an inclined position, squirt acetone into the upper end as the probe brush is being pushed with a twisting action through the probe; hold a sample container underneath the lower end of the probe, and catch any acetone and particulate matter which is brushed from the probe. Run the brush through the probe three times or more until no visible particulate matter is carried out with the acetone or until none remains in the probe liner on visual inspection. With stainless steel or other metal probes, run the brush through in the above prescribed manner at least six times since metal probes have small crevices in which particulate matter can be entrapped. Rinse the brush with acetone, and quantitatively collect these washings in the sample container. After the brushing, make a final acetone rinse of the probe as described above.

It is recommended that two people be used to clean the probe to minimize sample losses. Between sampling runs, keep brushes clean and protected from contamination.

After ensuring that all joints have been wiped clean of silicone grease, clean the inside of the front half of the filter holder by rubbing the surfaces with a nylon bristle brush and rinsing with acetone. Rinse each surface three times or more if needed to remove visible particulate. Make a final rinse of the brush and filter holder. Carefully rinse out the glass cyclone, also (if applicable). After all acetone washings and particulate matter have been collected in the sample container, tighten the lid on the sample container so that acetone will not leak out when it is shipped to the laboratory. Mark the height of the fluid level to determine whether or not leakage occurred during transport. Label the container to clearly identify its contents.

Container No. 3. Note the color of the indicating silica gel to determine if it has been completely spent and make a notation of its condition. Transfer the silica gel from the fourth impinger to its original container and seal. A funnel may make it easier to pour the silica gel without spilling. A rubber policeman may be used as an aid in removing the silica gel from the impinger. It is not necessary to remove the small amount of dust particles that may adhere to the impinger wall and are difficult to remove. Since the gain in weight is to be used for moisture calculations, do not use any water or other liquids to transfer the silica gel. If a balance is available in the field, follow the procedure for container No. 3 in Section 4.3.

Impinger Water. Treat the impingers as follows: Make a notation of any color or film in the liquid catch. Measure the liquid which is in the first three impingers to within ±1 ml by using a graduated cylinder or by weighing it to within ±0.5 g by using a balance (if one is available). Record the volume or weight of liquid present. This information is required to calculate the moisture content of the effluent gas.

Discard the liquid after measuring and recording the volume or weight, unless analysis of the impinger catch is required (see Note, Section 2.1.7).

If a different type of condenser is used, measure the amount of moisture condensed either volumetrically or gravimetrically.

Whenever possible, containers should be shipped in such a way that they remain upright at all times.

4.3 Analysis. Record the data required on a sheet such as the one shown in *Figure 5-3*. Handle each sample container as follows:

Container No. 1. Leave the contents in the shipping container or transfer the filter and any loose particulate from the sample container to a tared glass weighing dish. Desiccate for 24 hours in a desiccator containing anhydrous calcium sulfate. Weigh to a constant weight and report the results to the nearest 0.1 mg. For purposes of this Section, 4.3, the term "constant weight" means a difference of no more than 0.5 mg or 1 percent of total weight less tare weight, whichever is greater, between two consecutive weighings, with no less than 6 hours of desiccation time between weighings.

Plant ____________________

Date ____________________

Run No. ____________________

Filter No. ____________________

Amount liquid lost during transport ____________________

Acetone blank volume, ml ____________________

Acetone wash volume, ml ____________________

Acetone blank concentration, mg/mg (equation 5-4) ____________________

Acetone wash blank, mg (equation 5-5) ____________________

CONTAINER NUMBER	WEIGHT OF PARTICULATE COLLECTED, mg		
	FINAL WEIGHT	TARE WEIGHT	WEIGHT GAIN
1			
2			
TOTAL			
		Less acetone blank	
		Weight of particulate matter	

	VOLUME OF LIQUID WATER COLLECTED	
	IMPINGER VOLUME, ml	SILICA GEL WEIGHT, g
FINAL		
INITIAL		
LIQUID COLLECTED		
TOTAL VOLUME COLLECTED		g* ml

* CONVERT WEIGHT OF WATER TO VOLUME BY DIVIDING TOTAL WEIGHT INCREASE BY DENSITY OF WATER (1g/ml).

$$\frac{\text{INCREASE, g}}{1\ \text{g/ml}} = \text{VOLUME WATER, ml}$$

Figure 5-3. Analytical data.

Alternatively, the sample may be oven dried at 105° C (220° F) for 2 to 3 hours, cooled in the desiccator, and weighed to a constant weight, unless otherwise specified by the Administrator. The tester may also opt to oven dry the sample at 105° C (220° F) for 2 to 3 hours, weigh the sample, and use this weight as a final weight.

Container No. 2. Note the level of liquid in the container and confirm on the analysis sheet whether or not leakage occurred during transport. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Measure the liquid in this container either volumetrically to ±1 ml or gravimetrically to ±0.5 g. Transfer the contents to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a constant weight. Report the results to the nearest 0.1 mg.

Container No. 3. Weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g using a balance. This step may be conducted in the field.

"Acetone Blank" Container. Measure acetone in this container either volumetrically or gravimetrically. Transfer the acetone to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a constant weight. Report the results to the nearest 0.1 mg.

NOTE.—At the option of the tester, the contents of Container No. 2 as well as the acetone blank container may be evaporated at temperatures higher than ambient. If evaporation is done at an elevated temperature, the temperature must be below the boiling point of the solvent; also, to prevent "bumping," the evaporation process must be closely supervised, and the contents of the beaker must be swirled occasionally to maintain an even temperature. Use extreme care, as acetone is highly flammable and has a low flash point.

5. *Calibration*

Maintain a laboratory log of all calibrations.

5.1 Probe Nozzle. Probe nozzles shall be calibrated before their initial use in the field. Using a micrometer, measure the inside diameter of the nozzle to the nearest 0.025 mm (0.001 in.). Make three separate measurements using different diameters each time, and obtain the average of the measurements. The difference between the high and low numbers shall not exceed 0.1 mm (0.004 in.). When nozzles become nicked, dented, or corroded, they shall be reshaped, sharpened, and recalibrated before use. Each nozzle shall be permanently and uniquely identified.

5.2 Pitot Tube. The Type S pitot tube assembly shall be calibrated according to the procedure outlined in Section 4 of Method 2.

5.3 Metering System. Before its initial use in the field, the metering system shall be calibrated according to the procedure outlined in APTD-0576. Instead of physically adjusting the dry gas meter dial readings to correspond to the wet test meter readings, calibration factors may be used to mathematically correct the gas meter dial readings to the proper values. Before calibrating the metering system, it is suggested that a leak-check be conducted. For metering systems having diaphragm pumps, the normal leak-check procedure will not detect leakages within the pump. For these cases the following leak-check procedure is suggested: make a 10-minute calibration run at 0.00057 m³/min (0.02 cfm); at the end of the run, take the difference of the measured wet test meter and dry gas meter volumes; divide the difference by 10, to get the leak rate. The leak rate should not exceed 0.00057 m³/min (0.02 cfm).

After each field use, the calibration of the metering system shall be checked by performing three calibration runs at a single, intermediate orifice setting (based on the previous field test), with the vacuum set at the maximum value reached during the test series. To adjust the vacuum, insert a valve between the wet test meter and the inlet of the metering system. Calculate the average value of the calibration factor. If the calibration has changed by more than 5 percent, recalibrate the meter over the full range of orifice settings, as outlined in APTD-0576.

Alternative procedures, e.g., using the orifice meter coefficients, may be used, subject to the approval of the Administrator.

NOTE.—If the dry gas meter coefficient values obtained before and after a test series differ by more than 5 percent, the test series shall either be voided, or calculations for the test series shall be performed using whichever meter coefficient value (i.e., before or after) gives the lower value of total sample volume.

5.4 Probe Heater Calibration. The probe heating system shall be calibrated before its initial use in the field according to the procedure outlined in APTD-0576. Probes constructed according to APTD-0581 need not be calibrated if the calibration curves in APTD-0576 are used.

5.5 Temperature Gauges. Use the procedure in Section 4.3 of Method 2 to calibrate in-stack temperature gauges. Dial thermometers, such as are used for the dry gas meter and condenser outlet, shall be calibrated against mercury-in-glass thermometers.

5.6 Leak Check of Metering System Shown in Figure 5-1. That portion of the sampling train from the pump to the orifice meter should be leak checked prior to initial use and after each shipment. Leakage after the pump will result in less volume being recorded than is actually sampled. The following procedure is suggested (see Figure 5-4): Close the main valve on the meter box. Insert a one-hole rubber stopper with rubber tubing attached into the orifice exhaust pipe. Disconnect and vent the low side of the orifice manometer. Close off the low side orifice tap. Pressurize the system to 13 to 18 cm (5 to 7 in.) water column by blowing into the rubber tubing. Pinch off the tubing and observe the manometer for one minute. A loss of pressure on the manometer indicates a leak in the meter box; leaks, if present, must be corrected.

5.7 Barometer. Calibrate against a mercury barometer.

6. *Calculations*

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after the final calculation. Other forms of the equations may be used as long as they give equivalent results.

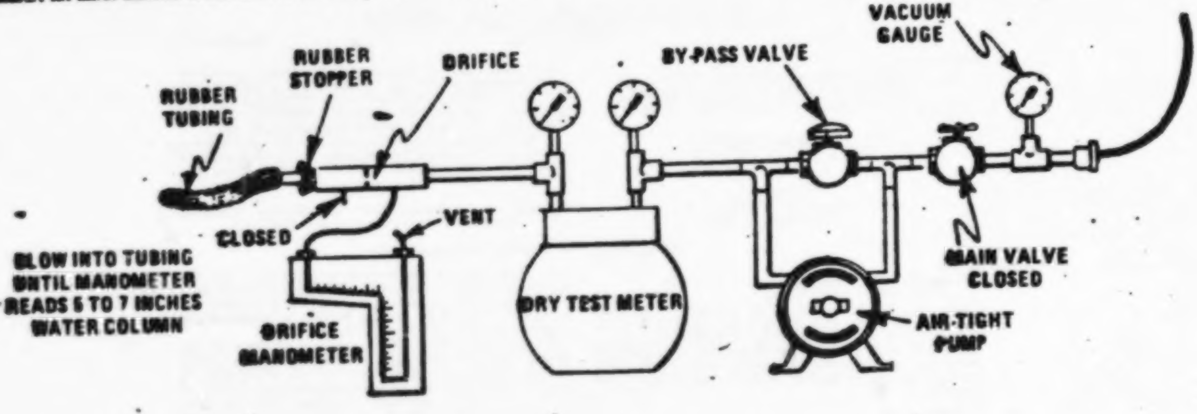

Figure 5-4. Leak check of meter box.

6.1 Nomenclature

A_n = Cross-sectional area of nozzle, m² (ft²).
B_{ws} = Water vapor in the gas stream, proportion by volume.
C_a = Acetone blank residue concentrations, mg/g.
c_s = Concentration of particulate matter in stack gas, dry basis, corrected to standard conditions, g/dscm (g/dscf).
I = Percent of isokinetic sampling.
L_a = Maximum acceptable leakage rate for either a pretest leak check or for a leak check following a component change; equal to 0.00057 m³/min (0.02 cfm) or 4 percent of the average sampling rate, whichever is less.
L_i = Individual leakage rate observed during the leak check conducted prior to the "i^{th}" component change (i=1, 2, 3 . . . . n), m³/min (cfm).
L_p = Leakage rate observed during the post-test leak check, m³/min (cfm).
m_n = Total amount of particulate matter collected, mg.
M_w = Molecular weight of water, 18.0 g/g-mole (18.0 lb/lb-mole).
m_a = Mass of residue of acetone after evaporation, mg.
P_{bar} = Barometric pressure at the sampling site, mm Hg (in. Hg).
P_s = Absolute stack gas pressure, mm Hg (in. Hg).
P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
R = Ideal gas constant, 0.06236 mm Hg-m³/°K-g-mole (21.85 in. Hg-ft³/°R-lb-mole).
T_m = Absolute average dry gas meter temperature (see Figure 5-2), °K (°R).
T_s = Absolute average stack gas temperature (see Figure 5-2), °K (°R).
T_{std} = Standard absolute temperature, 293° K (528° R).
V_a = Volume of acetone blank, ml.
V_{aw} = Volume of acetone used in wash, ml.
V_{lc} = Total volume of liquid collected in impingers and silica gel (see Figure 5-3), ml.
V_m = Volume of gas sample as measured by dry gas meter, dcm (dcf).
$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter, corrected to standard conditions, dscm (dscf).
$V_{w(std)}$ = Volume of water vapor in the gas sample, corrected to standard conditions, scm (scf).
v_s = Stack gas velocity, calculated by Method 2, Equation 2-9, using data obtained from Method 5, m/sec (ft/sec).
W_a = Weight of residue in acetone wash, mg.
Y = Dry gas meter calibration factor.
ΔH = Average pressure differential across the orifice meter (see Figure 5-2), mm H_2O (in. H_2O).
ρ_a = Density of acetone, mg/ml (see label on bottle).
ρ_w = Density of water, 0.9982 g/ml (0.002201 lb/ml).
θ = Total sampling time, min.
θ_1 = Sampling time interval, from the beginning of a run until the first component change, min.
θ_i = Sampling time interval, between two successive component changes, beginning with the interval between the first and second changes, min.
θ_p = Sampling time interval, from the final (n^{th}) component change until the end of the sampling run, min.
13.6 = Specific gravity of mercury.
60 = Sec/min.
100 = Conversion to percent.

6.2 Average dry gas meter temperature and average orifice pressure drop. See data sheet (Figure 5-2).

6.3 Dry Gas Volume. Correct the sample volume measured by the dry gas meter to standard conditions (20° C, 760 mm Hg or 68° F, 29.92 in. Hg) by using Equation 5-1.

$$V_{m(std)} = V_m Y \left(\frac{T_{std}}{T_m}\right)\left[\frac{P_{bar} + \frac{\Delta H}{13.6}}{P_{std}}\right]$$

$$= K_1 V_m Y \frac{P_{bar} + (\Delta H/13.6)}{T_m}$$

Equation 5-1

where:
K_1=0.3858 °K/mm Hg for metric units
=17.64 °R/in. Hg for English units

NOTE.—Equation 5-1 can be used as written unless the leakage rate observed during any of the mandatory leak checks (i.e., the post-test leak check or leak checks conducted prior to component changes) exceeds L_a. If L_p or L_i exceeds L_a, Equation 5-1 must be modified as follows:

(a) Case I. No component changes made during sampling run. In this case, replace V_m in Equation 5-1 with the expression:

$$\left[V_m-(L_p-L_a)\theta\right]$$

(b) Case II. One or more component changes made during the sampling run. In this case, replace V_m in Equation 5-1 by the expression:

$$\left[V_m-(L_1-L_a)\theta_1-\sum_{i=2}^{n}(L_i-L_a)\theta_i-(L_p-L_a)\theta_p\right]$$

and substitute only for those leakage rates (L_i or L_p) which exceed L_a.

6.4 Volume of water vapor.

Equation 5-2

$$V_{w(std)}=V_{lc}\left(\frac{\rho_w}{M_w}\right)\left(\frac{RT_{std}}{P_{std}}\right)=K_2V_{lc}$$

where:
K_2=0.001333 m³/ml for metric units
=0.04707 ft³/ml for English units.

6.5 Moisture Content.

$$B_{ws}=\frac{V_{w(std)}}{V_{m(std)}+V_{w(std)}}$$

Equation 5-3

NOTE.—In saturated or water droplet-laden gas streams, two calculations of the moisture content of the stack gas shall be made, one from the impinger analysis (Equation 5-3), and a second from the assumption of saturated conditions. The lower of the two values of B_{ws} shall be considered correct. The procedure for determining the moisture content based upon assumption of saturated conditions is given in the Note of Section 1.2 of Method 4. For the purposes of this method, the average stack gas temperature from Figure 5-2 may be used to make this determination, provided that the accuracy of the in-stack temperature sensor is ± 1° C (2° F).

6.6 Acetone Blank Concentration.

$$C_a=\frac{m_a}{V_a\rho_a}$$

Equation 5-4

6.7 Acetone Wash Blank.

$$W_a=C_aV_{aw}\rho_a$$

Equation 5-5

6.8 Total Particulate Weight. Determine the total particulate catch from the sum of the weights obtained from containers 1 and 2 less the acetone blank (see Figure 5-3). NOTE.—Refer to Section 4.1.5 to assist in calculation of results involving two or more filter assemblies or two or more sampling trains.

6.9 Particulate Concentration.

$$c_s=(0.001\ g/mg)\ (m_n/V_{m(std)})$$

Equation 5-6

6.10 Conversion Factors

From	To	Multiply by
scf	m³	0.02832
g/ft³	gr/ft³	15.43
g/ft³	lb/ft³	2.205×10⁻³
g/ft³	g/m³	35.31

6.11 Isokinetic Variation.

6.11.1 Calculation From Raw Data.

$$I=\frac{100\ T_s[K_3V_{lc}+(V_m/T_m)\ (P_{bar}+\Delta H/13.6)]}{60\ \theta v_s P_s A_n}$$

Equation 5-7

where:
K_3=0.003454 mm Hg−m³/ml−°K for metric units.
=0.002669 in. Hg−ft³/ml−°R for English units.

6.11.2 Calculation From Intermediate Values.

$$I=\frac{T_sV_{m(std)}P_{std}100}{T_{std}v_s\theta A_nP_s60(1-B_{ws})}$$

$$=K_4\frac{T_sV_{m(std)}}{P_sV_sA_n\theta(1-B_{ws})}$$

Equation 5-8

where:
K_4=4.320 for metric units
=0.09450 for English units.

6.12 Acceptable Results. If 90 percent $\leq I \leq$ 110 percent, the results are acceptable. If the results are low in comparison to the standard and I is beyond the acceptable range, or, if I is less than 90 percent, the Administrator may opt to accept the results. Use Citation 4 to make judgments. Otherwise, reject the results and repeat the test.

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METHOD 6—DETERMINATION OF SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES

1. *Principle and Applicability*.

1.1 Principle. A gas sample is extracted from the sampling point in the stack. The sulfuric acid mist (including sulfur trioxide) and the sulfur dioxide are separated. The sulfur dioxide fraction is measured by the barium-thorin titration method.

1.2 Applicability. This method is applicable for the determination of sulfur dioxide emissions from stationary sources. The minimum detectable limit of the method has been determined to be 3.4 milligrams (mg) of SO_2/m³ (2.12×10⁻⁷ lb/ft³). Although no upper limit has been established, tests have shown that concentrations as high as 80,000 mg/m³ of SO_2 can be collected efficiently in two midget impingers, each containing 15 milliliters of 3 percent hydrogen peroxide, at a rate of 1.0 lpm for 20 minutes. Based on theoretical calculations, the upper concentration limit in a 20-liter sample is about 93,300 mg/m³.

Possible interferents are free ammonia, water-soluble cations, and fluorides. The cations and fluorides are removed by glass wool filters and an isopropanol bubbler, and hence do not affect the SO_2 analysis. When samples are being taken from a gas stream with high concentrations of very fine metallic fumes (such as in inlets to control devices), a high-efficiency glass fiber filter must be used in place of the glass wool plug (i.e., the one in the probe) to remove the cation interferents.

Free ammonia interferes by reacting with SO_2 to form particulate sulfite and by reacting with the indicator. If free ammonia is present (this can be determined by knowledge of the process and noticing white particulate matter in the probe and isopropanol bubbler), alternative methods, subject to the approval of the Administrator, U.S. Environmental Protection Agency, are required.

2. *Apparatus*

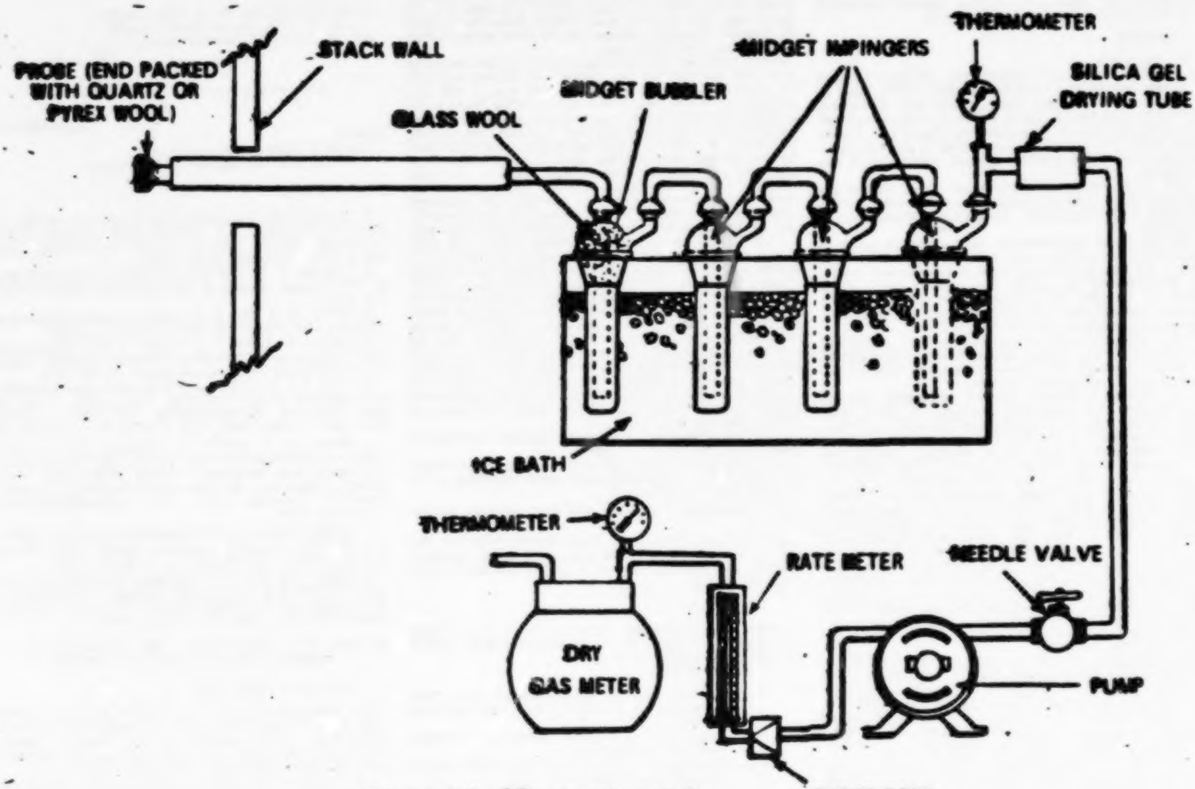

Figure 6-1. SO_2 sampling train.

2.1 Sampling. The sampling train is shown in Figure 6-1, and component parts are discussed below. The tester has the option of substituting sampling equipment described in Method 8 in place of the midget impinger equipment of Method 6. However, the Method 8 train must be modified to include a heated filter between the probe and isopropanol impinger, and the operation of the sampling train and sample analysis must be at the flow rates and solution volumes defined in Method 8.

The tester also has the option of determining SO_2 simultaneously with particulate matter and moisture determinations by (1) replacing the water in a Method 5 impinger system with 3 percent peroxide solution, or (2) by replacing the Method 5 water impinger system with a Method 8 isopropanol-filter-peroxide system. The analysis for SO_2 must be consistent with the procedure in Method 8.

2.1.1 Probe. Borosilicate glass, or stainless steel (other materials of construction may be used, subject to the approval of the Administrator), approximately 6-mm inside diameter, with a heating system to prevent water condensation and a filter (either in-stack or heated out-stack) to remove particulate matter, including sulfuric acid mist. A plug of glass wool is a satisfactory filter.

2.1.2 Bubbler and Impingers. One midget bubbler, with medium-coarse glass frit and borosilicate or quartz glass wool packed in top (see Figure 6-1) to prevent sulfuric acid mist carryover, and three 30-ml midget impingers. The bubbler and midget impingers must be connected in series with leak-free glass connectors. Silicone grease may be used, if necessary, to prevent leakage.

At the option of the tester, a midget impinger may be used in place of the midget bubbler.

Other collection absorbers and flow rates may be used, but are subject to the approval of the Administrator. Also, collection efficiency must be shown to be at least 99 percent for each test run and must be documented in the report. If the efficiency is found to be acceptable after a series of three tests, further documentation is not required. To conduct the efficiency test, an extra absorber must be added and analyzed separately. This extra absorber must not contain more than 1 percent of the total SO_2.

2.1.3 Glass Wool. Borosilicate or quartz.

2.1.4 Stopcock Grease. Acetone-insoluble, heat-stable silicone grease may be used, if necessary.

2.1.5 Temperature Gauge. Dial thermometer, or equivalent, to measure temperature of gas leaving impinger train to within 1° C (2° F.)

2.1.6 Drying Tube. Tube packed with 6- to 16-mesh indicating type silica gel, or equivalent, to dry the gas sample and to protect the meter and pump. If the silica gel has been used previously, dry at 175° C (350° F) for 2 hours. New silica gel may be used as received. Alternatively, other types of desiccants (equivalent or better) may be used, subject to approval of the Administrator.

2.1.7 Valve. Needle valve, to regulate sample gas flow rate.

2.1.8 Pump. Leak-free diaphragm pump, or equivalent, to pull gas through the train. Install a small tank between the pump and rate meter to eliminate the pulsation effect of the diaphragm pump on the rotameter.

2.1.9 Rate Meter. Rotameter, or equivalent, capable of measuring flow rate to within 2 percent of the selected flow rate of about 1000 cc/min.

2.1.10 Volume Meter. Dry gas meter, sufficiently accurate to measure the sample volume within 2 percent, calibrated at the selected flow rate and conditions actually encountered during sampling, and equipped with a temperature gauge (dial thermometer, or equivalent) capable of measuring temperature to within 3°C (5.4°F).

2.1.11 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg). In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice versa for elevation decrease.

2.1.12 Vacuum Gauge. At least 760 mm Hg (30 in. Hg) gauge, to be used for leak check of the sampling train.

2.2 Sample Recovery.

2.2.1 Wash bottles. Polyethylene or glass, 500 ml, two.

2.2.2 Storage Bottles. Polyethylene, 100 ml, to store impinger samples (one per sample).

2.3 Analysis.

2.3.1 Pipettes. Volumetric type, 5-ml, 20-ml (one per sample), and 25-ml sizes.

2.3.2 Volumetric Flasks. 100-ml size (one per sample) and 1000-ml size.

2.3.3 Burettes. 5- and 50-ml sizes.

2.3.4 Erlenmeyer Flasks. 250 ml-size (one for each sample, blank, and standard).

2.3.5 Dropping Bottle. 125-ml size, to add indicator.

2.3.6 Graduated Cylinder. 100-ml size.

2.3.7 Spectrophotometer. To measure absorbance at 352 nanometers.

3. Reagents

Unless otherwise indicated, all reagents must conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society. Where such specifications are not available, use the best available grade.

3.1 Sampling.

3.1.1 Water. Deionized, distilled to conform to ASTM specification D1193-74, Type 3. At the option of the analyst, the $KMnO_4$ test for oxidizable organic matter may be omitted when high concentrations of organic matter are not expected to be present.

3.1.2 Isopropanol, 80 percent. Mix 80 ml of isopropanol with 20 ml of deionized, distilled water. Check each lot of isopropanol for peroxide impurities as follows: shake 10 ml of isopropanol with 10 ml of freshly prepared 10 percent potassium iodide solution. Prepare a blank by similarly treating 10 ml of distilled water. After 1 minute, read the absorbance at 352 nanometers on a spectrophotometer. If absorbance exceeds 0.1, reject alcohol for use.

Peroxides may be removed from isopropanol by redistilling or by passage through a column of activated alumina; however, reagent grade isopropanol with suitably low peroxide levels may be obtained from commercial sources. Rejection of contaminated lots may, therefore, be a more efficient procedure.

3.1.3 Hydrogen Peroxide, 3 Percent. Dilute 30 percent hydrogen peroxide 1:9 (v/v) with deionized, distilled water (30 ml is needed per sample). Prepare fresh daily.

3.1.4 Potassium Iodide Solution, 10 Percent. Dissolve 10.0 grams KI in deionized, distilled water and dilute to 100 ml. Prepare when needed.

3.2 Sample Recovery.

3.2.1 Water. Deionized, distilled, as in 3.1.1.

3.2.2 Isopropanol, 80 Percent. Mix 80 ml of isopropanol with 20 ml of deionized, distilled water.

3.3 Analysis.

3.3.1 Water. Deionized, distilled, as in 3.1.1.

3.3.2 Isopropanol, 100 percent.

3.3.3 Thorin Indicator. 1-(o-arsonophenylazo)-2-naphthol-3,6-disulfonic acid, disodium salt, or equivalent. Dissolve 0.20 g in 100 ml of deionized, distilled water.

3.3.4 Barium Perchlorate Solution, 0.0100 N. Dissolve 1.95 g of barium perchlorate trihydrate [$Ba(ClO_4)_2 \cdot 3H_2O$] in 200 ml distilled water and dilute to 1 liter with isopropanol. Alternatively, 1.22 g of [$BaCl_2 \cdot 2H_2O$] may be used instead of the perchlorate. Standardize as in Section 5.5.

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3.3.5 Sulfuric Acid Standard, 0.0100 N. Purchase or standardize to ±0.0002 N against 0.0100 N NaOH which has previously been standardized against potassium acid phthalate (primary standard grade).

4. *Procedure.*

4.1 Sampling.

4.1.1 Preparation of collection train. Measure 15 ml of 80 percent isopropanol into the midget bubbler and 15 ml of 3 percent hydrogen peroxide into each of the first two midget impingers. Leave the final midget impinger dry. Assemble the train as shown in Figure 6-1. Adjust probe heater to a temperature sufficient to prevent water condensation. Place crushed ice and water around the impingers.

4.1.2 Leak-check procedure. A leak check prior to the sampling run is optional; however, a leak check after the sampling run is mandatory. The leak-check procedure is as follows:

With the probe disconnected, place a vacuum gauge at the inlet to the bubbler and pull a vacuum of 250 mm (10 in.) Hg; plug or pinch off the outlet of the flow meter, and then turn off the pump. The vacuum shall remain stable for at least 30 seconds. Carefully release the vacuum gauge before releasing the flow meter end to prevent back flow of the impinger fluid.

Other leak check procedures may be used, subject to the approval of the Administrator, U.S. Environmental Protection Agency. The procedure used in Method 5 is not suitable for diaphragm pumps.

4.1.3 Sample collection. Record the initial dry gas meter reading and barometric pressure. To begin sampling, position the tip of the probe at the sampling point, connect the probe to the bubbler, and start the pump. Adjust the sample flow to a constant rate of approximately 1.0 liter/min as indicated by the rotameter. Maintain this constant rate (±10 percent) during the entire sampling run. Take readings (dry gas meter, temperatures at dry gas meter and at impinger outlet and rate meter) at least every 5 minutes. Add more ice during the run to keep the temperature of the gases leaving the last impinger at 20° C (68° F) or less. At the conclusion of each run, turn off the pump, remove probe from the stack, and record the final readings. Conduct a leak check as in Section 4.1.2. (This leak check is mandatory.) If a leak is found, void the test run. Drain the ice bath, and purge the remaining part of the train by drawing clean ambient air through the system for 15 minutes at the sampling rate.

Clean ambient air can be provided by passing air through a charcoal filter or through an extra midget impinger with 15 ml of 3 percent H_2O_2. The tester may opt to simply use ambient air, without purification.

4.2 Sample Recovery. Disconnect the impingers after purging. Discard the contents of the midget bubbler. Pour the contents of the midget impingers into a leak-free polyethylene bottle for shipment. Rinse the three midget impingers and the connecting tubes with deionized, distilled water, and add the washings to the same storage container. Mark the fluid level. Seal and identify the sample container.

4.3 Sample Analysis. Note level of liquid in container, and confirm whether any sample was lost during shipment; note this on analytical data sheet. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results.

Transfer the contents of the storage container to a 100-ml volumetric flask and dilute to exactly 100 ml with deionized, distilled water. Pipette a 20-ml aliquot of this solution into a 250-ml Erlenmeyer flask, add 80 ml of 100 percent isopropanol and two to four drops of thorin indicator, and titrate to a pink endpoint using 0.0100 N barium perchlorate. Repeat and average the titration volumes. Run a blank with each series of samples. Replicate titrations must agree within 1 percent or 0.2 ml, whichever is larger.

(NOTE.—Protect the 0.0100 N barium perchlorate solution from evaporation at all times.)

5. *Calibration*

5.1 Metering System.

5.1.1 Initial Calibration. Before its initial use in the field, first leak check the metering system (drying tube, needle valve, pump, rotameter, and dry gas meter) as follows: place a vacuum gauge at the inlet to the drying tube and pull a vacuum of 250 mm (10 in.) Hg; plug or pinch off the outlet or the flow meter, and then turn off the pump. The vacuum shall remain stable for at least 30 seconds. Carefully release the vacuum gauge before releasing the flow meter end.

Next, calibrate the metering system (at the sampling flow rate specified by the method) as follows: connect an appropriately sized wet test meter (e.g., 1 liter per revolution) to the inlet of the drying tube. Make three independent calibration runs, using at least five revolutions of the dry gas meter per run. Calculate the calibration factor, Y (wet test meter calibration volume divided by the dry gas meter volume, both volumes adjusted to the same reference temperature and pressure), for each run, and average the results. If any Y value deviates by more than 2 percent from the average, the metering system is unacceptable for use. Otherwise, use the average as the calibration factor for subsequent test runs.

5.1.2 Post-Test Calibration Check. After each field test series, conduct a calibration check as in Section 5.1.1 above, except for the following variations: (a) the leak check is not to be conducted, (b) three, or more revolutions of the dry gas meter may be used, and (c) only two independent runs need be made. If the calibration factor does not deviate by more than 5 percent from the initial calibration factor (determined in Section 5.1.1), then the dry gas meter volumes obtained during the test series are acceptable. If the calibration factor deviates by more than 5 percent, recalibrate the metering system as in Section 5.1.1, and for the calculations, use the calibration factor (initial or recalibration) that yields the lower gas volume for each test run.

5.2 Thermometers. Calibrate against mercury-in-glass thermometers.

5.3 Rotameter. The rotameter need not be calibrated but should be cleaned and maintained according to the manufacturer's instruction.

5.4 Barometer. Calibrate against a mercury barometer.

5.5 Barium Perchlorate Solution. Standardize the barium perchlorate solution against 25 ml of standard sulfuric acid to which 100 ml of 100 percent isopropanol has been added.

6. *Calculations*

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation.

6.1 Nomenclature.

C_{SO_2} = Concentration of sulfur dioxide, dry basis corrected to standard conditions, mg/dscm (lb/dscf).
N = Normality of barium perchlorate titrant, milliequivalents/ml.
P_{bar} = Barometric pressure at the exit orifice of the dry gas meter, mm Hg (in. Hg).
P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
T_m = Average dry gas meter absolute temperature, °K (°R).
T_{std} = Standard absolute temperature, 293° K (528° R).
V_a = Volume of sample aliquot titrated, ml.
V_m = Dry gas volume as measured by the dry gas meter, dcm (dcf).
$V_{m(std)}$ = Dry gas volume measured by the dry gas meter, corrected to standard conditions, dscm (dscf).
V_{soln} = Total volume of solution in which the sulfur dioxide sample is contained, 100 ml.
V_t = Volume of barium perchlorate titrant used for the sample, ml (average of replicate titrations).
V_{tb} = Volume of barium perchlorate titrant used for the blank, ml.
Y = Dry gas meter calibration factor.
32.03 = Equivalent weight of sulfur dioxide.

6.2 Dry sample gas volume, corrected to standard conditions.

$$V_{m(std)} = V_m Y \left(\frac{T_{std}}{T_m}\right)\left(\frac{P_{bar}}{P_{std}}\right) = K_1 Y \frac{V_m P_{bar}}{T_m}$$

Equation 6-1

where:

K_1 = 0.3858 °K/mm Hg for metric units.
= 17.64 °R/in. Hg for English units.

6.3 Sulfur dioxide concentration.

$$C_{SO_2} = K_2 \frac{(V_t - V_{tb})\, N \left(\frac{V_{soln}}{V_a}\right)}{V_{m(std)}}$$

Equation 6-2

where:

K_2 = 32.03 mg/meq. for metric units.
= 7.061×10⁻⁵ lb/meq. for English units.

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METHOD 7—DETERMINATION OF NITROGEN OXIDE EMISSIONS FROM STATIONARY SOURCES

1. *Principle and Applicability*

1.1 Principle. A grab sample is collected in an evacuated flask containing a dilute sulfuric acid-hydrogen peroxide absorbing solution, and the nitrogen oxides, except nitrous oxide, are measured colorimetrically using the phenoldisulfonic acid (PDS) procedure.

1.2 Applicability. This method is applicable to the measurement of nitrogen oxides emitted from stationary sources. The range of the method has been determined to be 2 to 400 milligrams NO_x (as NO_2) per dry standard cubic meter, without having to dilute the sample.

2. *Apparatus*

2.1 Sampling (see Figure 7-1). Other grab sampling systems or equipment, capable of measuring sample volume to within ±2.0 percent and collecting a sufficient sample volume to allow analytical reproducibility to within ±5 percent, will be considered acceptable alternatives, subject to approval of the Administrator, U.S. Environmental Protection Agency. The following equipment is used in sampling:

2.1.1 Probe. Borosilicate glass tubing, sufficiently heated to prevent water condensation and equipped with an in-stack or out-stack filter to remove particulate matter (a plug of glass wool is satisfactory for this purpose). Stainless steel or Teflon[1] tubing may also be used for the probe. Heating is not necessary if the probe remains dry during the purging period.

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[1] Mention of trade names or specific products does not constitute endorsement by the Environmental Protection Agency.

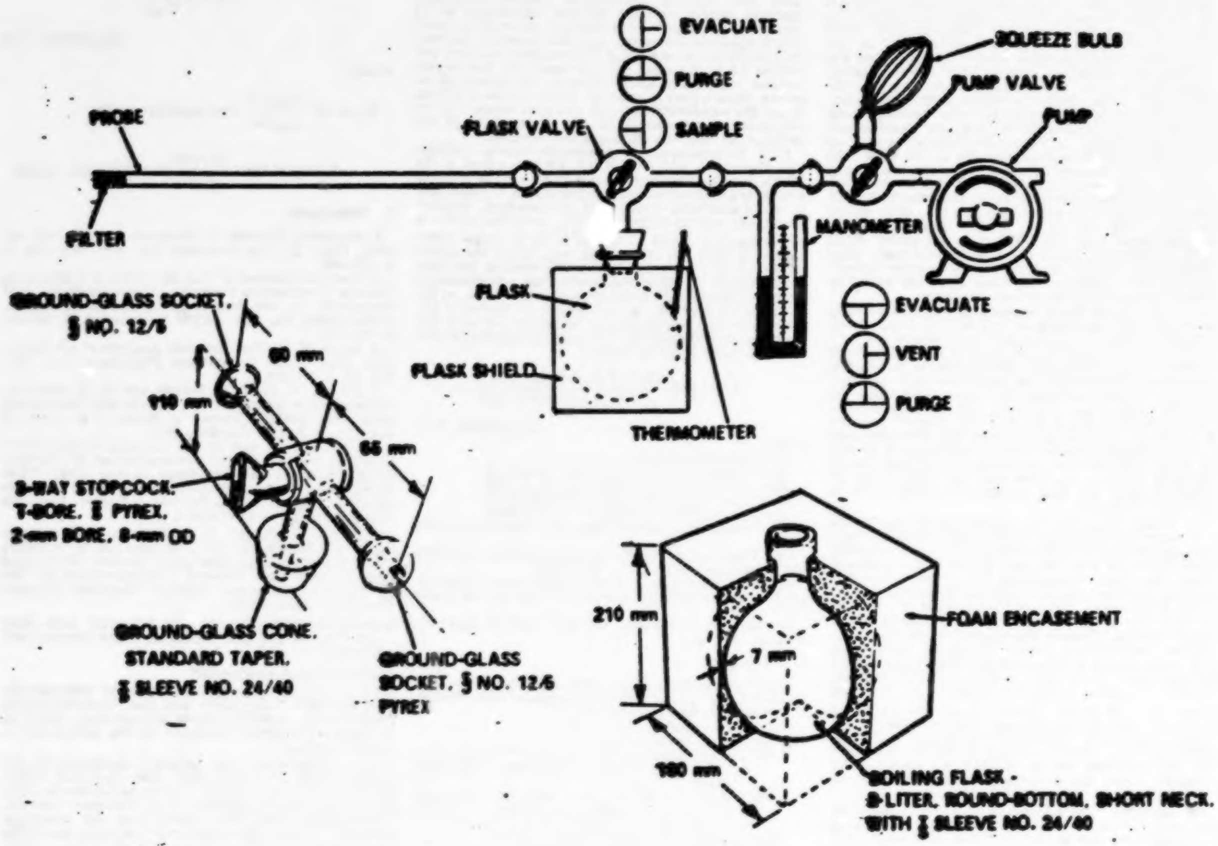
EVACUATE
PURGE
SAMPLE
SQUEEZE BULB
PUMP VALVE
PUMP
PROBE
FLASK VALVE
FILTER
MANOMETER
FLASK
FLASK SHIELD
THERMOMETER
EVACUATE
VENT
PURGE
GROUND-GLASS SOCKET, § NO. 12/5
80 mm
110 mm
65 mm
3-WAY STOPCOCK: T-BORE, § PYREX, 2-mm BORE, 8-mm OD
GROUND-GLASS CONE, STANDARD TAPER, § SLEEVE NO. 24/40
GROUND-GLASS SOCKET, § NO. 12/5 PYREX
210 mm
7 mm
FOAM ENCASEMENT
190 mm
BOILING FLASK - 2-LITER, ROUND-BOTTOM, SHORT NECK, WITH § SLEEVE NO. 24/40

Figure 7-1. Sampling train, flask valve, and flask.

2.1.2 Collection Flask. Two-liter borosilicate, round bottom flask, with short neck and 24/40 standard taper opening, protected against implosion or breakage.

2.1.3 Flask Valve. T-bore stopcock connected to a 24/40 standard taper joint.

2.1.4 Temperature Gauge. Dial-type thermometer, or other temperature gauge, capable of measuring 1° C (2° F) intervals from −5 to 50° C (25 to 125° F).

2.1.5 Vacuum Line. Tubing capable of withstanding a vacuum of 75 mm Hg (3 in. Hg) absolute pressure, with "T" connection and T-bore stopcock.

2.1.6 Vacuum Gauge. U-tube manometer, 1 meter (36 in.), with 1-mm (0.1-in.) divisions, or other gauge capable of measuring pressure to within ±2.5 mm Hg (0.10 in. Hg).

2.1.7 Pump. Capable of evacuating the collection flask to a pressure equal to or less than 75 mm Hg (3 in. Hg) absolute.

2.1.8 Squeeze Bulb. One-way.

2.1.9 Volumetric Pipette. 25 ml.

2.1.10 Stopcock and Ground Joint Grease. A high-vacuum, high-temperature chlorofluorocarbon grease is required. Halocarbon 25-5S has been found to be effective.

2.1.11 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg). In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase, or vice versa for elevation decrease.

2.2 Sample Recovery. The following equipment is required for sample recovery:

2.2.1 Graduated Cylinder. 50 ml with 1-ml divisions.

2.2.2 Storage Containers. Leak-free polyethylene bottles.

2.2.3 Wash Bottle. Polyethylene or glass.

2.2.4 Glass Stirring Rod.

2.2.5 Test Paper for Indicating pH. To cover the pH range of 7 to 14.

2.3 Analysis. For the analysis, the following equipment is needed:

2.3.1 Volumetric Pipettes. Two 1 ml, two 2 ml, one 3 ml, one 4 ml, two 10 ml, and one 25 ml for each sample and standard.

2.3.2 Porcelain Evaporating Dishes. 175- to 250-ml capacity with lip for pouring, one for each sample and each standard. The Coors No. 45006 (shallow-form, 195 ml) has been found to be satisfactory. Alternatively, polymethyl pentene beakers (Nalge No. 1203, 150 ml), or glass beakers (150 ml) may be used. When glass beakers are used, etching of the beakers may cause solid matter to be present in the analytical step; the solids should be removed by filtration (see Section 4.3).

2.3.3 Steam Bath. Low-temperature ovens or thermostatically controlled hot plates kept below 70° C (160° F) are acceptable alternatives.

2.3.4 Dropping Pipette or Dropper. Three required.

2.3.5 Polyethylene Policeman. One for each sample and each standard.

2.3.6 Graduated Cylinder. 100 ml with 1-ml divisions.

2.3.7 Volumetric Flasks. 50 ml (one for each sample), 100 ml (one for each sample and each standard, and one for the working standard KNO_3 solution), and 1000 ml (one).

2.3.8 Spectrophotometer. To measure absorbance at 410 nm.

2.3.9 Graduated Pipette. 10 ml with 0.1-ml divisions.

2.3.10 Test Paper for Indicating pH. To cover the pH range of 7 to 14.

2.3.11 Analytical Balance. To measure to within 0.1 mg.

3. Reagents

Unless otherwise indicated, it is intended that all reagents conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available; otherwise, use the best available grade.

3.1 Sampling. To prepare the absorbing solution, cautiously add 2.8 ml concentrated H_2SO_4 to 1 liter of deionized, distilled water. Mix well and add 6 ml of 3 percent hydrogen peroxide, freshly prepared from 30 percent hydrogen peroxide solution. The absorbing solution should be used within 1 week of its preparation. Do not expose to extreme heat or direct sunlight.

3.2 Sample Recovery. Two reagents are required for sample recovery:

3.2.1 Sodium Hydroxide (1N). Dissolve 40 g NaOH in deionized, distilled water and dilute to 1 liter.

3.2.2 Water. Deionized, distilled to conform to ASTM specification D1193-74, Type 3. At the option of the analyst, the $KMnO_4$ test for oxidizable organic matter may be omitted when high concentrations of organic matter are not expected to be present.

3.3 Analysis. For the analysis, the following reagents are required:

3.3.1 Fuming Sulfuric Acid. 15 to 18 percent by weight free sulfur trioxide. HANDLE WITH CAUTION.

3.3.2 Phenol. White solid.

3.3.3 Sulfuric Acid. Concentrated, 95 percent minimum assay. HANDLE WITH CAUTION.

3.3.4 Potassium Nitrate. Dried at 105 to 110° C (220 to 230° F) for a minimum of 2 hours just prior to preparation of standard solution.

3.3.5 Standard KNO_3 Solution. Dissolve exactly 2.198 g of dried potassium nitrate (KNO_3) in deionized, distilled water and dilute to 1 liter with deionized, distilled water in a 1,000-ml volumetric flask.

3.3.6 Working Standard KNO_3 Solution. Dilute 10 ml of the standard solution to 100 ml with deionized distilled water. One milliliter of the working standard solution is equivalent to 100 μg nitrogen dioxide (NO_2).

3.3.7 Water. Deionized, distilled as in Section 3.2.2.

3.3.8 Phenoldisulfonic Acid Solution. Dissolve 25 g of pure white phenol in 150 ml concentrated sulfuric acid on a steam bath. Cool, add 75 ml fuming sulfuric acid, and heat at 100° C (212° F) for 2 hours. Store in a dark, stoppered bottle.

4. Procedure

4.1 Sampling.

4.1.1 Pipette 25 ml of absorbing solution into a sample flask, retaining a sufficient quantity for use in preparing the calibration standards. Insert the flask valve stopper into the flask with the valve in the "purge" position. Assemble the sampling train as shown in Figure 7-1 and place the probe at the sampling point. Make sure that all fittings are tight and leak-free, and that all ground glass joints have been properly greased with a high-vacuum, high-temperature chlorofluorocarbon-based stopcock grease. Turn the flask valve and the pump valve to their "evacuate" positions. Evacuate the flask to 75 mm Hg (3 in. Hg) absolute pressure, or less. Evacuation to a pressure approaching the vapor pressure of water at the existing temperature is desirable. Turn the pump valve to its "vent" position and turn off the pump. Check for leakage by observing the manometer for any pressure fluctuation. (Any variation greater than 10 mm Hg (0.4 in. Hg) over a period of 1 minute is not acceptable, and the flask is not to be used until the leakage problem is corrected. Pressure in the flask is not to exceed 75 mm Hg (3 in. Hg) absolute at the time sampling is commenced.) Record the volume of the flask and valve (V_f), the flask temperature (T_i), and the barometric pressure. Turn the flask valve counterclockwise to its "purge" position and do the same with the pump valve. Purge the probe and the vacuum tube using the squeeze bulb. If condensation occurs in the probe and the flask valve area, heat the probe and purge until the condensation disappears. Next, turn the pump valve to its "vent" position. Turn the flask valve clockwise to its "evacuate" position and record the difference in the mercury levels in the manometer. The absolute internal pressure in the flask (P_i) is equal to the barometric pressure less the manometer reading. Immediately turn the flask valve to the "sample" position and permit the gas to enter the flask until pressures in the flask and sample line (i.e., duct, stack) are equal. This will usually require about 15 seconds; a longer period indicates a "plug" in the probe, which must be corrected before sampling is continued. After collecting the sample, turn the flask valve to its "purge" position and disconnect the flask from the sampling train. Shake the flask for at least 5 minutes.

4.1.2 If the gas being sampled contains insufficient oxygen for the conversion of NO to NO_2 (e.g., an applicable subpart of the standard may require taking a sample of a calibration gas mixture of NO in N_2), then oxygen shall be introduced into the flask to permit this conversion. Oxygen may be introduced into the flask by one of three methods; (1) Before evacuating the sampling flask, flush with pure cylinder oxygen, then evacuate flask to 75 mm Hg (3 in. Hg) absolute pressure or less; or (2) inject oxygen into the flask after sampling; or (3) terminate sampling with a minimum of 50 mm Hg (2 in. Hg) vacuum remaining in the flask, record this final pressure, and then vent the flask to the atmosphere until the flask pressure is almost equal to atmospheric pressure.

4.2 Sample Recovery. Let the flask set for a minimum of 16 hours and then shake the contents for 2 minutes. Connect the flask to a mercury filled U-tube manometer. Open the valve from the flask to the manometer and record the flask temperature (T_f), the barometric pressure, and the difference between the mercury levels in the manometer. The absolute internal pressure in the flask (P_f) is the barometric pressure less the manometer reading. Transfer the contents of the flask to a leak-free polyethylene bottle. Rinse the flask twice with 5-ml portions of deionized, distilled water and add the rinse water to the bottle. Adjust the pH to between 9 and 12 by adding sodium hydroxide (1 N), dropwise (about 25 to 35 drops). Check the pH by dipping a stirring rod into the solution and then touching the rod to the pH test paper. Remove as little material as possible during this step. Mark the height of the liquid level so that the container can be checked for leakage after transport. Label the container to clearly identify its contents. Seal the container for shipping.

4.3 Analysis. Note the level of the liquid in container and confirm whether or not any sample was lost during shipment; note this on the analytical data sheet. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Immediately prior to analysis, transfer the contents of the shipping container to a 50-ml volumetric flask, and rinse the container twice with 5-ml portions of deionized, distilled water. Add the rinse water to the flask and dilute to the mark with deionized, distilled water; mix thoroughly. Pipette a 25-ml aliquot into the procelain evaporating dish. Return any unused portion of the sample to the polyethylene storage bottle. Evaporate the 25-ml aliquot to dryness on a steam bath and allow to cool. Add 2 ml phenoldisulfonic acid solution to the dried residue and triturate thoroughly with a poylethylene policeman. Make sure the solution contacts all the residue. Add 1 ml deionized, distilled water and four drops of concentrated sulfuric acid. Heat the solution on a steam bath for 3 minutes with occasional stirring. Allow the solution to cool, add 20 ml deionized, distilled water, mix well by stirring, and add concentrated ammonium hydroxide, dropwise, with constant stirring, until the pH is 10 (as determined by pH paper). If the sample contains solids, these must be removed by filtration (centrifugation is an acceptable alternative, subject to the approval of the Administrator), as follows: filter through Whatman No. 41 filter paper into a 100-ml volumetric flask; rinse the evaporating dish with three 5-ml portions of deionized, distilled water; filter these three rinses. Wash the filter with at least three 15-ml portions of deionized, distilled water. Add the filter washings to the contents of the volumetric flask and dilute to the mark with deionized, distilled water. If solids are absent, the solution can be transferred directly to the 100-ml volumetric flask and diluted to the mark with deionized, distilled water. Mix the contents of the flask thoroughly, and measure the absorbance at the optimum wavelength used for the standards (Section 5.2.1), using the blank solution as a zero reference. Dilute the sample and the blank with equal volumes of deionized, distilled water if the absorbance exceeds A_4, the absorbance of the 400 μg NO_2 standard (see Section 5.2.2).

5. *Calibration*

5.1 Flask Volume. The volume of the collection flask-flask valve combination must be known prior to sampling. Assemble the flask and flask valve and fill with water, to the stopcock. Measure the volume of water to ±10 ml. Record this volume on the flask.

5.2 Spectrophotometer Calibration.

5.2.1 Optimum Wavelength Determination. For both fixed and variable wavelength spectrophotometers, calibrate against standard certified wavelength of 410 nm, every 6 months. Alternatively, for variable wave length spectrophotometers, scan the spectrum between 400 and 415 nm using a 200 μg NO_2 standard solution (see Section 5.2.2). If a peak does not occur, the spectrophotometer is probably malfunctioning, and should be repaired. When a peak is obtained within the 400 to 415 nm range, the wavelength at which this peak occurs shall be the optimum wavelength for the measurement of absorbance for both the standards and samples.

5.2.2 Determination of Spectrophotometer Calibration Factor K_c. Add 0.0, 1.0, 2.0, 3.0, and 4.0 ml of the KNO_3 working standard solution (1 ml = 100 μg NO_2) to a series of five porcelain evaporating dishes. To each, add 25 ml of absorbing solution, 10 ml deionized, distilled water, and sodium hydroxide (1N), dropwise, until the pH is between 9 and 12 (about 25 to 35 drops each). Beginning with the evaporation step, follow the analysis procedure of Section 4.3, until the solution has been transferred to the 100 ml volumetric flask and diluted to the mark. Measure the absorbance of each solution, at the optimum wavelength, as determined in Section 5.2.1. This calibration procedure must be repeated on each day that samples are analysed. Calculate the spectrophotometer calibration factor as follows:

$$K_c = 100\,\frac{A_1+2A_2+3A_3+4A_4}{A_1^2+A_2^2+A_3^2+A_4^2}$$

Equation 7-1

where:

K_c = Calibration factor
A_1 = Absorbance of the 100-μg NO_2 standard
A_2 = Absorbance of the 200-μg NO_2 standard
A_3 = Absorbance of the 300-μg NO_2 standard
A_4 = Absorbance of the 400-μg NO_2 standard

5.3 Barometer. Calibrate against a mercury barometer.

5.4 Temperature Gauge. Calibrate dial thermometers against mercury-in-glass thermometers.

5.5 Vacuum Gauge. Calibrate mechanical gauges, if used, against a mercury manometer such as that specified in 2.1.6.

5.6 Analytical Balance. Calibrate against standard weights.

6. *Calculations*

Carry out the calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculations.

6.1 Nomenclature.

A = Absorbance of sample.
C = Concentration of NO_x as NO_2, dry basis, corrected to standard conditions, mg/dscm (lb/dscf).
F = Dilution factor (i.e., 25/5, 25/10, etc., required only if sample dilution was needed to reduce the absorbance into the range of calibration).
K_c = Spectrophotometer calibration factor.
m = Mass of NO_x as NO_2 in gas sample, μg.
P_f = Final absolute pressure of flask, mm Hg (in. Hg).
P_i = Initial absolute pressure of flask, mm Hg (in. Hg).
P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
T_f = Final absolute temperature of flask, °K (°R).
T_i = Initial absolute temperature of flask, °K (°R).
T_{std} = Standard absolute temperature, 293° K (528° R)
V_{sc} = Sample volume at standard conditions (dry basis), ml.
V_f = Volume of flask and valve, ml.
V_a = Volume of absorbing solution, 25 ml.
2 = 50/25, the aliquot factor. (If other than a 25-ml aliquot was used for analysis, the corresponding factor must be substituted).

6.2 Sample volume, dry basis, corrected to standard conditions.

$$V_{sc} = \frac{T_{std}}{P_{std}}\,(V_f - V_a)\left[\frac{P_f}{T_f} - \frac{P_i}{T_i}\right]$$

$$= K_1(V_f - 25\text{ ml})\left[\frac{P_f}{T_f} - \frac{P_i}{T_i}\right]$$

Equation 7-2

where:

$$K_1 = 0.3858\,\frac{°\text{K}}{\text{mm Hg}}\text{ for metric units}$$

$$= 17.64\,\frac{°\text{R}}{\text{in. Hg}}\text{ for English units}$$

6.3 Total μg NO_2 per sample.

$$m = 2\,K_c\,AF$$

Equation 7-3

NOTE.—If other than a 25-ml aliquot is used for analysis, the factor 2 must be replaced by a corresponding factor.

6.4 Sample concentration, dry basis, corrected to standard conditions.

$$C = K_2\,\frac{m}{V_{sc}}$$

Equation 7-4

where:

$$K_2 = 10^3\,\frac{\text{mg/m}^3}{\mu\text{g/ml}}\text{ for metric units}$$

$$= 6.243\times10^{-5}\,\frac{\text{lb/scf}}{\mu\text{g/ml}}\text{ for English units}$$

7. *Bibliography*

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METHOD 8—DETERMINATION OF SULFURIC ACID MIST AND SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES

1. *Principle and Applicability*

1.1 Principle. A gas sample is extracted isokinetically from the stack. The sulfuric acid mist (including sulfur trioxide) and the sulfur dioxide are separated, and both fractions are measured separately by the barium-thorin titration method.

1.2 Applicability. This method is applicable for the determination of sulfuric acid mist (including sulfur trioxide, and in the absence of other particulate matter) and sulfur dioxide emissions from stationary sources. Collaborative tests have shown that the minimum detectable limits of the method are 0.05 milligrams/cubic meter (0.03×10^{-7} pounds/cubic foot) for sulfur trioxide and 1.2 mg/m³ (0.74×10^{-7} lb/ft³) for sulfur dioxide. No upper limits have been established. Based on theoretical calculations for 200 milliliters of 3 percent hydrogen peroxide solution, the upper concentration limit for sulfur dioxide in a 1.0 m³ (35.3 ft³) gas sample is about 12,500 mg/m³ (7.7×10^{-4} lb/ft³). The upper limit can be extended by increasing the quantity of peroxide solution in the impingers.

Possible interfering agents of this method are fluorides, free ammonia, and dimethyl aniline. If any of these interfering agents are present (this can be determined by knowledge of the process), alternative methods, subject to the approval of the Administrator, are required.

Filterable particulate matter may be determined along with SO_3 and SO_2 (subject to the approval of the Administrator); however, the procedure used for particulate matter must be consistent with the specifications and procedures given in Method 5.

2. *Apparatus*

2.1 Sampling. A schematic of the sampling train used in this method is shown in Figure 8-1; it is similar to the Method 5 train except that the filter position is different and the filter holder does not have to be heated. Commercial models of this train are available. For those who desire to build their own, however, complete construction details are described in APTD-0581. Changes from the APTD-0581 document and allowable modifications to Figure 8-1 are discussed in the following subsections.

The operating and maintenance procedures for the sampling train are described in APTD-0576. Since correct usage is important in obtaining valid results, all users should read the APTD-0576 document and adopt the operating and maintenance procedures outlined in it, unless otherwise specified herein. Further details and guidelines on operation and maintenance are given in Method 5 and should be read and followed whenever they are applicable.

2.1.1 Probe Nozzle. Same as Method 5, Section 2.1.1.

2.1.2 Probe Liner. Borosilicate or quartz glass, with a heating system to prevent visible condensation during sampling. Do not use metal probe liners.

2.1.3 Pitot Tube. Same as Method 5, Section 2.1.3.

2.2.5 Sulfuric Acid Standard (0.0100 N). Purchase or standardize to ±0.0002 N against 0.0100 N NaOH that has previously been standardized against primary standard potassium acid phthalate.

4. *Procedure*

4.1 Sampling.

4.1.1 Pretest Preparation. Follow the procedure outlined in Method 5, Section 4.1.1; filters should be inspected, but need not be desiccated, weighed, or identified. If the effluent gas can be considered dry, i.e., moisture free, the silica gel need not be weighed.

4.1.2 Preliminary Determinations. Follow the procedure outlined in Method 5, Section 4.1.2.

4.1.3 Preparation of Collection Train. Follow the procedure outlined in Method 5, Section 4.1.3 (except for the second paragraph and other obviously inapplicable parts) and use Figure 8-1 instead of Figure 5-1. Replace the second paragraph with: Place 100 ml of 80 percent isopropanol in the first impinger, 100 ml of 3 percent hydrogen peroxide in both the second and third impingers; retain a portion of each reagent for use as a blank solution. Place about 200 g of silica gel in the fourth impinger.

NOTE.—If moisture content is to be determined by impinger analysis, weigh each of the first three impingers (plus absorbing solution) to the nearest 0.5 g and record these weights. The weight of the silica gel (or silica gel plus container) must also be determined to the nearest 0.5 g and recorded.

4.1.4 Pretest Leak-Check Procedure. Follow the basic procedure outlined in Method 5, Section 4.1.4.1, noting that the probe heater shall be adjusted to the minimum temperature required to prevent condensation, and also that verbage such as, "* * * plugging the inlet to the filter holder * * *," shall be replaced by, "* * * plugging the inlet to the first impinger * * *." The pretest leak-check is optional.

4.1.5 Train Operation. Follow the basic procedures outlined in Method 5, Section 4.1.5, in conjunction with the following special instructions. Data shall be recorded on a sheet similar to the one in Figure 8-2. The sampling rate shall not exceed 0.030 m³/min (1.0 cfm) during the run. Periodically during the test, observe the connecting line between the probe and first impinger for signs of condensation. If it does occur, adjust the probe heater setting upward to the minimum temperature required to prevent condensation. If component changes become necessary during a run, a leak-check shall be done immediately before each change, according to the procedure outlined in Section 4.1.4.2 of Method 5 (with appropriate modifications, as mentioned in Section 4.1.4 of this method); record all leak rates. If the leakage rate(s) exceed the specified rate, the tester shall either void the run or shall plan to correct the sample volume as outlined in Section 6.3 of Method 5. Immediately after component changes, leak-checks are optional. If these leak-checks are done, the procedure outlined in Section 4.1.4.1 of Method 5 (with appropriate modifications) shall be used.

PLANT __________
LOCATION __________
OPERATOR __________
DATE __________
RUN NO. __________
SAMPLE BOX NO. __________
METER BOX NO. __________
METER ΔH@ __________
C FACTOR __________
PITOT TUBE COEFFICIENT, Cp __________

SCHEMATIC OF STACK CROSS SECTION

STATIC PRESSURE, mm Hg (in. Hg) __________
AMBIENT TEMPERATURE __________
BAROMETRIC PRESSURE __________
ASSUMED MOISTURE, % __________
PROBE LENGTH, m (ft) __________
NOZZLE IDENTIFICATION NO. __________
AVERAGE CALIBRATED NOZZLE DIAMETER, cm (in.) __________
PROBE HEATER SETTING __________
LEAK RATE, m³/min, (cfm) __________
PROBE LINER MATERIAL __________
FILTER NO. __________

TRAVERSE POINT NUMBER	SAMPLING TIME (θ), min.	VACUUM mm Hg (in. Hg)	STACK TEMPERATURE (T_S), °C (°F)	VELOCITY HEAD (ΔP_S), mm H_2O (in. H_2O)	PRESSURE DIFFERENTIAL ACROSS ORIFICE METER, mm H_2O (in. H_2O)	GAS SAMPLE VOLUME, m³ (ft³)	GAS SAMPLE TEMPERATURE AT DRY GAS METER		TEMPERATURE OF GAS LEAVING CONDENSER OR LAST IMPINGER, °C (°F)
							INLET, °C (°F)	OUTLET, °C (°F)	
TOTAL							Avg	Avg	
AVERAGE							Avg		

Figure 8-2. Field data.

After turning off the pump and recording the final readings at the conclusion of each run, remove the probe from the stack. Conduct a post-test (mandatory) leak-check as in Section 4.1.4.3 of Method 5 (with appropriate modification) and record the leak rate. If the post-test leakage rate exceeds the specified acceptable rate, the tester shall either correct the sample volume, as outlined in Section 6.3 of Method 5, or shall void the run.

Drain the ice bath and, with the probe disconnected, purge the remaining part of the train, by drawing clean ambient air through the system for 15 minutes at the average flow rate used for sampling.

NOTE.—Clean ambient air can be provided by passing air through a charcoal filter. At the option of the tester, ambient air (without cleaning) may be used.

4.1.6 Calculation of Percent Isokinetic. Follow the procedure outlined in Method 5, Section 4.1.6.

4.2 Sample Recovery.

4.2.1 Container No. 1. If a moisture content analysis is to be done, weigh the first impinger plus contents to the nearest 0.5 g and record this weight.

Transfer the contents of the first impinger to a 250-ml graduated cylinder. Rinse the probe, first impinger, all connecting glassware before the filter, and the front half of the filter holder with 80 percent isopropanol. Add the rinse solution to the cylinder. Dilute to 250 ml with 80 percent isopropanol. Add the filter to the solution, mix, and transfer to the storage container. Protect the solution against evaporation. Mark the level of liquid on the container and identify the sample container.

4.2.2 Container No. 2. If a moisture content analysis is to be done, weigh the second and third impingers (plus contents) to the nearest 0.5 g and record these weights. Also, weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g.

Transfer the solutions from the second and third impingers to a 1000-ml graduated cylinder. Rinse all connecting glassware (including back half of filter holder) between the filter and silica gel impinger with deionized, distilled water, and add this rinse water to the cylinder. Dilute to a volume of 1000 ml with deionized, distilled water. Transfer the solution to a storage container. Mark the level of liquid on the container. Seal and identify the sample container.

4.3 Analysis.

Note the level of liquid in containers 1 and 2, and confirm whether or not any sample was lost during shipment; note this on the analytical data sheet. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results.

4.3.1 Container No. 1. Shake the container holding the isopropanol solution and the filter. If the filter breaks up, allow the fragments to settle for a few minutes before removing a sample. Pipette a 100-ml aliquot of this solution into a 250-ml Erlenmeyer flask, add 2 to 4 drops of thorin indicator, and titrate to a pink endpoint using 0.0100 N barium perchlorate. Repeat the titration with a second aliquot of sample and average the titration

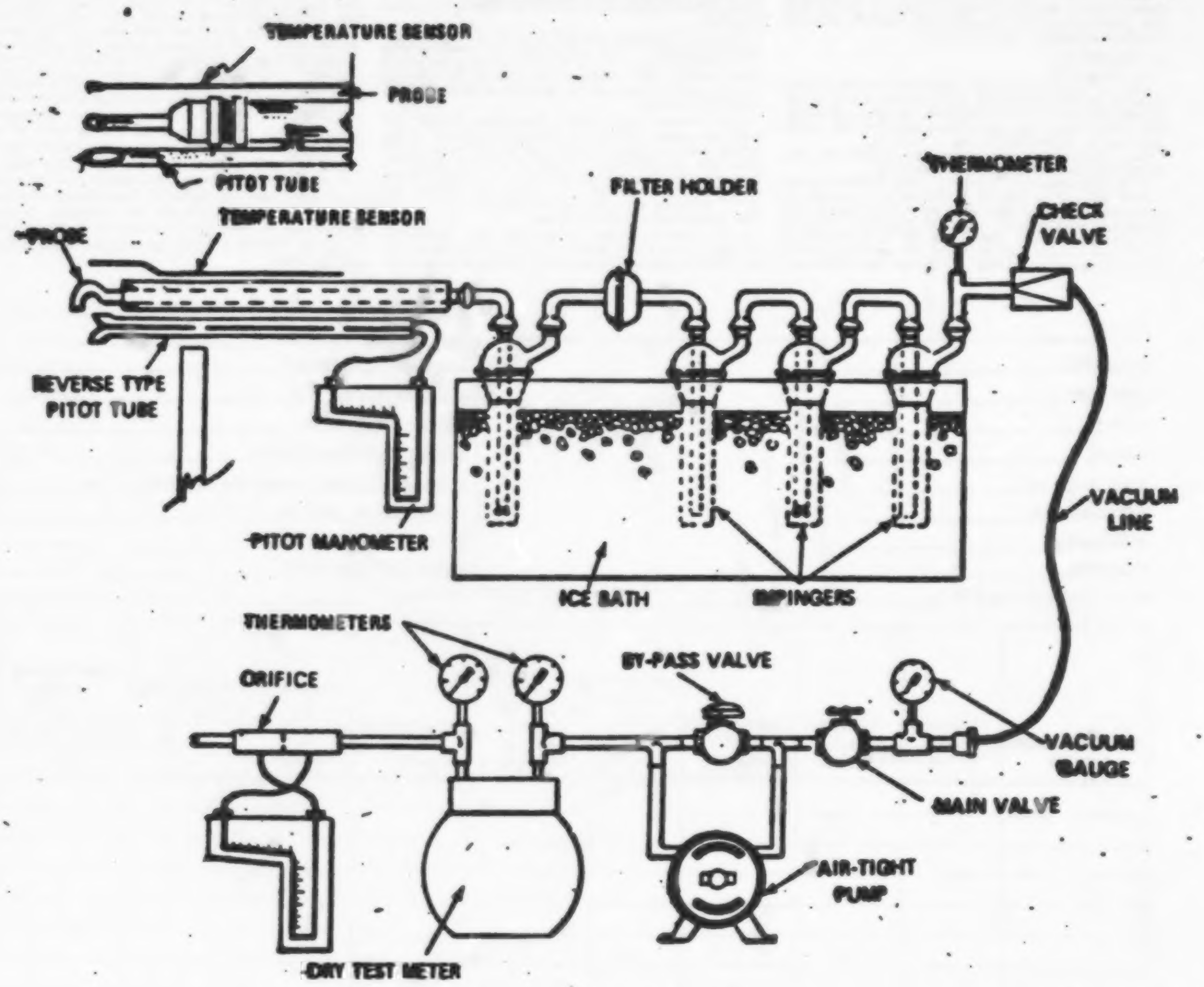

Figure 8-1. Sulfuric acid mist sampling train.

2.1.4 Differential Pressure Gauge. Same as Method 5, Section 2.1.4.

2.1.5 Filter Holder. Borosilicate glass, with a glass frit filter support and a silicone rubber gasket. Other gasket materials, e.g., Teflon or Viton, may be used subject to the approval of the Administrator. The holder design shall provide a positive seal against leakage from the outside or around the filter. The filter holder shall be placed between the first and second impingers. Note: Do not heat the filter holder.

2.1.6 Impingers—Four, as shown in Figure 8-1. The first and third shall be of the Greenburg-Smith design with standard tips. The second and fourth shall be of the Greenburg-Smith design, modified by replacing the insert with an approximately 13 millimeter (0.5 in.) ID glass tube, having an unconstricted tip located 13 mm (0.5 in.) from the bottom of the flask. Similar collection systems, which have been approved by the Administrator, may be used.

2.1.7 Metering System. Same as Method 5, Section 2.1.8.

2.1.8 Barometer. Same as Method 5, Section 2.1.9.

2.1.9 Gas Density Determination Equipment. Same as Method 5, Section 2.1.10.

2.1.10 Temperature Gauge. Thermometer, or equivalent, to measure the temperature of the gas leaving the impinger train to within 1° C (2° F).

2.2 Sample Recovery.

2.2.1 Wash Bottles. Polyethylene or glass, 500 ml. (two).

2.2.2 Graduated Cylinders. 250 ml, 1 liter. (Volumetric flasks may also be used.)

2.2.3 Storage Bottles. Leak-free polyethylene bottles, 1000 ml size (two for each sampling run).

2.2.4 Trip Balance. 500-gram capacity, to measure to ±0.5 g (necessary only if a moisture content analysis is to be done).

2.3 Analysis.

2.3.1 Pipettes. Volumetric 25 ml, 100 ml.

2.3.2 Burrette. 50 ml.

2.3.3 Erlenmeyer Flask. 250 ml. (one for each sample blank and standard).

2.3.4 Graduated Cylinder. 100 ml.

2.3.5 Trip Balance. 500 g capacity, to measure to ±0.5 g.

2.3.6 Dropping Bottle. To add indicator solution, 125-ml size.

3. Reagents

Unless otherwise indicated, all reagents are to conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Otherwise, use the best available grade.

3.1 Sampling.

3.1.1 Filters. Same as Method 5, Section 3.1.1.

3.1.2 Silica Gel. Same as Method 5, Section 3.1.2.

3.1.3 Water. Deionized, distilled to conform to ASTM specification D1193-74, Type 3. At the option of the analyst, the $KMnO_4$ test for oxidizable organic matter may be omitted when high concentrations of organic matter are not expected to be present.

3.1.4 Isopropanol, 80 Percent. Mix 800 ml of isopropanol with 200 ml of deionized, distilled water.

NOTE.—Experience has shown that only A.C.S. grade isopropanol is satisfactory. Tests have shown that isopropanol obtained from commercial sources occasionally has peroxide impurities that will cause erroneously high sulfuric acid mist measurement. Use the following test for detecting peroxides in each lot of isopropanol: Shake 10 ml of the isopropanol with 10 ml of freshly prepared 10 percent potassium iodide solution. Prepare a blank by similarly treating 10 ml of distilled water. After 1 minute, read the absorbance on a spectrophotometer at 352 nanometers. If the absorbance exceeds 0.1, the isopropanol shall not be used. Peroxides may be removed from isopropanol by redistilling, or by passage through a column of activated alumina. However, reagent-grade isopropanol with suitably low peroxide levels is readily available from commercial sources; therefore, rejection of contaminated lots may be more efficient than following the peroxide removal procedure.

3.1.5 Hydrogen Peroxide, 3 Percent. Dilute 100 ml of 30 percent hydrogen peroxide to 1 liter with deionized, distilled water. Prepare fresh daily.

3.1.6 Crushed Ice.

3.2 Sample Recovery.

3.2.1 Water. Same as 3.1.3.

3.2.2 Isopropanol, 80 Percent. Same as 3.1.4.

3.3 Analysis.

3.3.1 Water. Same as 3.1.3.

3.3.2 Isopropanol, 100 Percent.

3.3.3 Thorin Indicator. 1-(o-arsonophenylazo)-2-naphthol-3, 6-disulfonic acid, disodium salt, or equivalent. Dissolve 0.20 g in 100 ml of deionized, distilled water.

3.3.4 Barium Perchlorate (0.0100 Normal). Dissolve 1.95 g of barium perchlorate trihydrate ($Ba(ClO_4)_2 \cdot 3H_2O$) in 200 ml deionized, distilled water, and dilute to 1 liter with isopropanol. 1.22 g of barium chloride dihydrate ($BaCl_2 \cdot 2H_2O$) may be used instead of the barium perchlorate. Standardize with sulfuric acid as in Section 5.2. This solution must be protected against evaporation at all times.

values. Replicate titrations must agree within 1 percent or 0.2 ml, whichever is greater.

4.3.2 Container No. 2. Thoroughly mix the solution in the container holding the contents of the second and third impingers. Pipette a 10-ml aliquot of sample into a 250-ml Erlenmeyer flask. Add 40 ml of isopropanol, 2 to 4 drops of thorin indicator, and titrate to a pink endpoint using 0.0100 N barium perchlorate. Repeat the titration with a second aliquot of sample and average the titration values. Replicate titrations must agree within 1 percent or 0.2 ml, whichever is greater.

4.3.3 Blanks. Prepare blanks by adding 2 to 4 drops of thorin indicator to 100 ml of 80 percent isopropanol. Titrate the blanks in the same manner as the samples.

5. *Calibration*

5.1 Calibrate equipment using the procedures specified in the following sections of Method 5: Section 5.3 (metering system); Section 5.5 (temperature gauges); Section 5.7 (barometer). Note that the recommended leak-check of the metering system, described in Section 5.6 of Method 5, also applies to this method.

5.2 Standardize the barium perchlorate solution with 25 ml of standard sulfuric acid, to which 100 ml of 100 percent isopropanol has been added.

6. *Calculations*

Note.—Carry out calculations retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation.

6.1 Nomenclature.

A_n = Cross-sectional area of nozzle, m² (ft²).
B_{ws} = Water vapor in the gas stream, proportion by volume.
$C_{H_2SO_4}$ = Sulfuric acid (including SO_3) concentration, g/dscm (lb/dscf).
C_{SO_2} = Sulfur dioxide concentration, g/dscm (lb/dscf).
I = Percent of isokinetic sampling.
N = Normality of barium perchlorate titrant, g equivalents/liter.
P_{bar} = Barometric pressure at the sampling site, mm Hg (in. Hg).
P_s = Absolute stack gas pressure, mm Hg (in. Hg).
P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
T_m = Average absolute dry gas meter temperature (see Figure 8-2), ° K (° R).
T_s = Average absolute stack gas temperature (see Figure 8-2), ° K (° R).
T_{std} = Standard absolute temperature, 293° K (528° R).
V_a = Volume of sample aliquot titrated, 100 ml for H_2SO_4 and 10 ml for SO_2.
V_{1c} = Total volume of liquid collected in impingers and silica gel, ml.
V_m = Volume of gas sample as measured by dry gas meter, dcm (dcf).
$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter corrected to standard conditions, dscm (dscf).
v_s = Average stack gas velocity, calculated by Method 2, Equation 2-9, using data obtained from Method 8, m/sec (ft/sec).
V_{soln} = Total volume of solution in which the sulfuric acid or sulfur dioxide sample is contained, 250 ml or 1,000 ml, respectively.
V_t = Volume of barium perchlorate titrant used for the sample, ml.
V_{tb} = Volume of barium perchlorate titrant used for the blank, ml.
Y = Dry gas meter calibration factor.
ΔH = Average pressure drop across orifice meter, mm (in.) H_2O.
θ = Total sampling time, min.
13.6 = Specific gravity of mercury.
60 = sec/min.
100 = Conversion to percent.

6.2 Average dry gas meter temperature and average orifice pressure drop. See data sheet (Figure 8-2).

6.3 Dry Gas Volume. Correct the sample volume measured by the dry gas meter to standard conditions (20° C and 760 mm Hg or 68° F and 29.92 in. Hg) by using Equation 8-1.

$$V_{m(std)} = V_m Y \left(\frac{T_{std}}{T_m}\right) \frac{P_{bar} + \left(\frac{\Delta H}{13.6}\right)}{P_{std}}$$

$$= K_1 V_m Y \frac{P_{bar} + (\Delta H/13.6)}{T_m}$$

Equation 8-1

where:
K_1 = 0.3858 °K/mm Hg for metric units.
= 17.64 °R/in. Hg for English units.

Note.—If the leak rate observed during any mandatory leak-checks exceeds the specified acceptable rate, the tester shall either correct the value of V_m in Equation 8-1 (as described in Section 6.3 of Method 5), or shall invalidate the test run.

6.4 Volume of Water Vapor and Moisture Content. Calculate the volume of water vapor using Equation 5-2 of Method 5; the weight of water collected in the impingers and silica gel can be directly converted to milliliters (the specific gravity of water is 1 g/ml). Calculate the moisture content of the stack gas, using Equation 5-3 of Method 5. The "Note" in Section 6.5 of Method 5 also applies to this method. Note that if the effluent gas stream can be considered dry, the volume of water vapor and moisture content need not be calculated.

6.5 Sulfuric acid mist (including SO_3) concentration.

$$C_{H_2SO_4} = K_2 \frac{N(V_t - V_{tb})\left(\frac{V_{soln}}{V_a}\right)}{V_{m(std)}}$$

Equation 8-2

where:
K_2 = 0.04904 g/milliequivalent for metric units.
= 1.081×10^{-4} lb/meq for English units.

6.6 Sulfur dioxide concentration.

$$C_{SO_2} = K_3 \frac{N(V_t - V_{tb})\left(\frac{V_{soln}}{V_a}\right)}{V_{m(std)}}$$

Equation 8-3

where:
K_3 = 0.03203 g/meq for metric units.
= 7.061×10^{-5} lb/meq for English units.

6.7 Isokinetic Variation.

6.7.1 Calculation from raw data.

$$I = \frac{100\, T_s [K_4 V_{1c} + (V_m / T_m) P_{bar} + \Delta H/13.6)]}{60\, \theta V_s P_s A_n}$$

Equation 8-4

where:
K_4 = 0.003464 mm Hg-m³/ml-°K for metric units.
= 0.002676 in. Hg-ft³/ml-°R for English units.

6.7.2 Calculation from intermediate values.

$$I = \frac{T_s V_{m(std)} P_{std}\, 100}{T_{std} v_s \theta A_n P_s\, 60\, (1 - B_{ws})}$$

$$= K_5 \frac{T_s V_{m(std)}}{P_s v_s A_n \theta (1 - B_{ws})}$$

Equation 8-5

where:
K_5 = 4.320 for metric units.
= 0.09450 for English units.

6.8 Acceptable Results. If 90 percent ≤I ≤110 percent, the results are acceptable. If the results are low in comparison to the standards and I is beyond the acceptable range, the Administrator may opt to accept the results. Use Citation 4 in the Bibliography of Method 5 to make judgments. Otherwise, reject the results and repeat the test.

7. *Bibliography*

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7. Annual Book of ASTM Standards. Part 31; Water, Atmospheric Analysis. pp. 40-42. American Society for Testing and Materials. Philadelphia, Pa. 1974.

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(Secs. 111, 114, 301(a), Clean Air Act, sec. 4(a) of Pub. L. 91-604, 84 Stat. 1683; sec. 4(a) of Pub. L. 91-604, 84 Stat. 1687; sec. 2 of Pub. L. 90-148, 81 Stat. 504 [42 U.S.C. 1857c-6, 1857c-9, 1857g(a)].)

[FR Doc.77-13606 Filed 8-17-77;8:45 am]

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APPENDIX E

PEDCo ENVIRONMENTAL, INC.

MEMORANDUM

TO: Project File

DATE: August 8, 1977

SUBJECT: Trip Report - Visit to Magma Copper Company, San Manuel, Arizona on 7/22/77

FROM: V. Katari

FILE: 3287-B

cc: L. Yerino
T. Devitt
R. Gerstle

After visiting the Phelps-Dodge Copper Company at Ajo, Arizona, on July 21, 1977, Larry Yerino and I drove to Tucson, Arizona, with Larry Bowerman and Bill Thurston of EPA Region IX. The following day, we were joined by Steve Schwartz of BAQC, and all of us visited the Magma Copper Company at San Manuel, Arizona.

Larry Bowerman explained the purpose of our visit during a brief meeting attended by the following people:

Bill Wood - Magma Copper Company
J. D. McCaine - Magma Copper Company
Art Verdugo - Magma Copper Company
F. C. Davis - Magma Copper Company
D. C. Ridinger - Magma Copper Company
Mike McCarthy - Magma Copper Company
Dale E. Zabel - Magma Copper Company
Ralph Sievwright - Attorney for Magma Copper Company
Larry Bowerman - EPA, Region IX
Bill Thurston - EPA, Region IX
Steve Schwartz - BAQC
Larry Yerino - PEDCo Environmental, Inc.
Vishnu Katari - PEDCo Environmental, Inc.

As stated during the meeting, the purpose of the visit was to inspect reverberatory furnace operations at the smelter, including charging practices and the flue gas handling and control system, and also to survey the available space for an add-on emission control system in the vicinity of the current system.

Art Verdugo and Mike McCarthy of Magma showed us the reverberatory furnace and its emission control system. All three reverberatory furnaces were in operation during our inspection. Furnace No. 1 was being charged with concentrate delivered by a conveyor belt system. An operator manually opened the furnace doors on the side (three at a time) to allow the concentrate to drop into the furnace. As each charge dropped into the furnace, it produced a big cloud of dust.

The three reverberatory furnaces are located in parallel, from south to north. After the concentrate is mixed with precipitator dust, limerock, and flux, it is stored in gravity-type feeders. It is transported from storage to the furnaces by conveyor system. The addition of converter slag to the concentrate is necessary because it aids in the formation of a bottom bed in the furnace. Matte, the furnace product, is tapped near the center of the furnace, is gravity-fed into laddles, and then is moved to the converter area. The slag formed in the furnace is tapped near one end of the furnace and flows into slag pots, which are hauled by rail car to the slag dump.

Exhaust gases from each furnace pass through a set of two waste-heat boilers into a common balloon flue, then through an electrostatic precipitator header to three independent electrostatic precipitator units. The treated gases pass into a common header and then are vented through a natural draft stack operating at a negative pressure of from 2.0 to 2.5 inches water. A manually controlled header installed underneath the gas header collects any dust carryover. A bypass duct connects the balloon flue to the common header for the treated gases. A duct system is installed to take a bleed stream of treated gases to an SCRA* pilot plant, which is not operating at present.

Each electrostatic precipitator consists of three fields, and two hoppers, is equipped with inlet and outlet dampers, and each ESP can perform independently. According to Magma personnel, each precipitator inlet is installed with one diffusion plate. They do not know, however, whether the transformer-rectifier (TR) units are working efficiently, or whether any air infiltration sources are present in the entire gas handling and treatment system.

Heavy material collected in the waste-heat boilers is charged to the converter, and fine dust is charged to the reverberatory furnace. The ducts are periodically cleaned to remove settled dust. The matte and slag areas are hooded, and the collected gases are exhausted directly to individual stacks. Magma personnel believe that particulate emissions from matte tapping are negligible; therefore, they have never conducted particulate testing under the hood system. Some sulfur dioxide may be emitted from the tapping hood area.

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* Smelter Control Research Association.

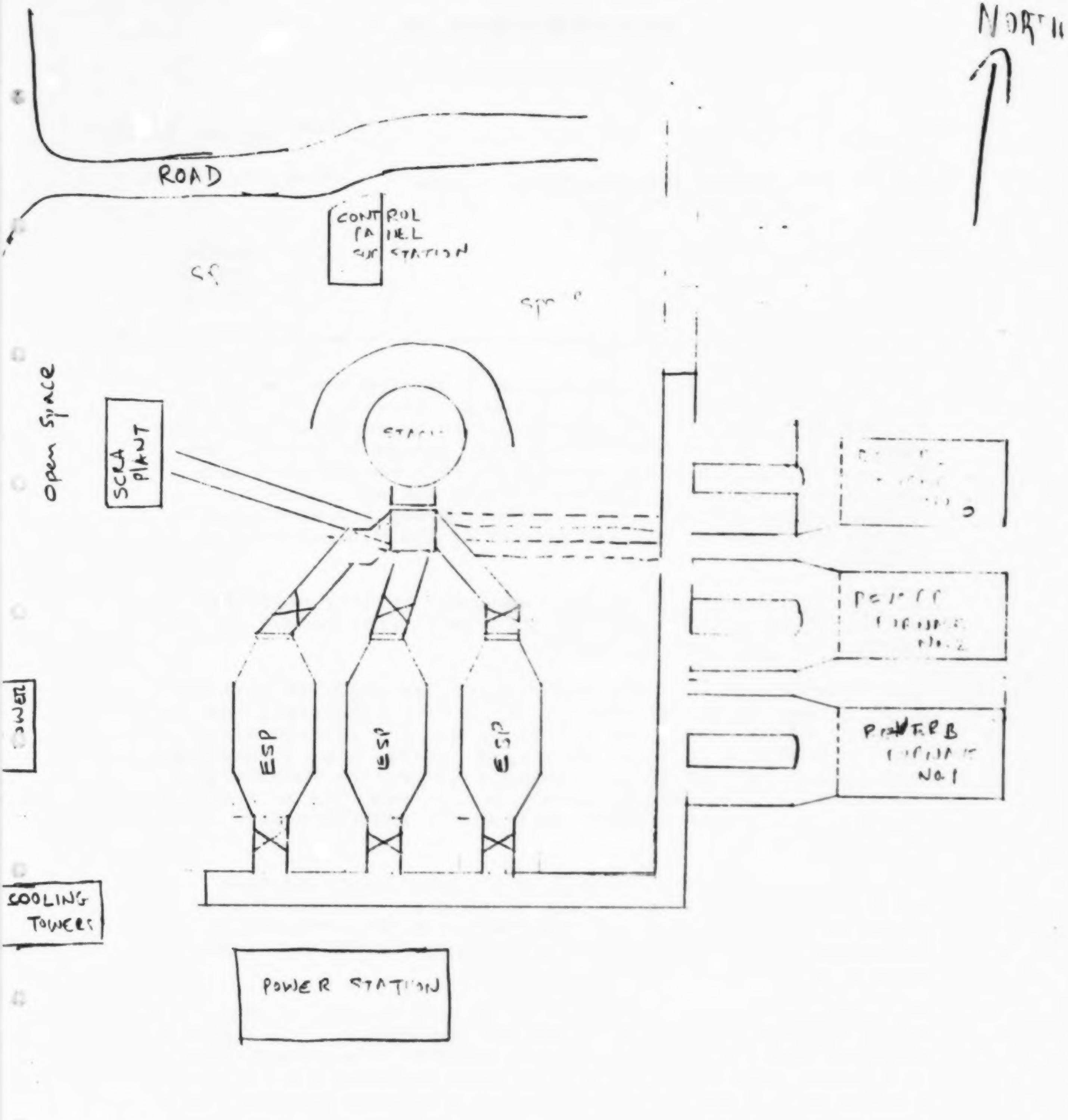
Magma personnel indicated they have never tried to pelletize the converter slag before adding it to the reverberatory furnace.

Usually five converters are operated and one is held as a spare during the operation of all three reverberatory furnaces.

Magma is planning to convert their reverberatory furnaces from oil and gas firing to coal firing. They predict that they may have to improve the waste-heat boiler system and flue gas handling system. They are also prepared to install any required add-on control system. The EPA Region IX informed Magma that the facility will be subject to NSPS regulations. EPA is planning to conduct particulate sampling on the reverberatory furnaces before and after conversion to coal. The Arizona EPA in planning to conduct particulate sampling on September 12 and 13, 1977.

Our inspection revealed that enough space is available in the vicinity of the current control system and stack to install any necessary add-on equipment. The following figure (not in scale) depicts the location of the current control system and indicates the space available for add-on equipment.

Magma will make available to PEDCo (through EPA Region IX) general drawings of the current particulate control system and different material stream analyses.


NORTH
ROAD
CONTROL
PANEL
SUBSTATION
Open Space
SCRA PLANT
STACK
ESP
ESP
ESP
REVERB FURNACE No. 2
REVERB FURNACE No 1
TOWER
COOLING TOWERS
POWER STATION

REVERBERATORY FURNACES AND THEIR CONTROL SYSTEM LOCATION— [illegible] COPPER COMPANY

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PEDCo ENVIRONMENTAL, INC.

MEMORANDUM

TO: Project File

DATE: August 3, 1977

SUBJECT: Trip Report - Phelps-Dodge Copper Company, Ajo on 7/21/77

FROM: V. Katari

FILE: 3287-B

cc: L. Yerino
T. Devitt
R. Gerstle

On July 21, 1977, Larry Yerino and I visited the Phelps-Dodge Copper Company at Ajo, Arizona. Messrs. Larry Bowerman and Bill Thurston of EPA Region IX accompanied us to the plant and Mr. Steve Schwartz of BAQC joined us there. The purpose of the visit was to acquire data on the reverberatory furnace operating procedures and the air pollution control equipment operation, and to survey the available space for an add-on control system in the vicinity of the current control equipment.

Mr. F. R. Rickard, the smelter manager, briefly described the reverberatory furnace operation and later showed us the furnace and its control system.

The reverberatory furnace burners are designed for burning natural gas, or diesel oil, or No. 6 oil. The plant has not been operating because of a strike, but the reverberatory furnace has been kept hot by firing natural gas, a necessary step to keep the silica arc support inside the furnace from falling down; rebuilding the arc would require 4 to 5 weeks. Phelps-Dodge Copper Company maintains a smelter repair team at the plant.

Phelps-Dodge Copper Company at Ajo, usually smelts concentrate prepared from its own mined ore; however, custom concentrates are sometimes smelted on an optional basis, depending upon the furnace availability (production never exceeds design capacity).

The concentrate is brought to the plant, stored in cans, and taken through a double arc gate to the hopper. Its typical moisture content is 6 1/2 to 7.0 percent. The concentrate is charged onto a variable-speed belt conveyor and is dropped into a small feed hopper of a slinger machine. Lime rock addition to the furnace is continuous. The flue dust collected in the reverberatory furnace electrostatic precipitator is recycled back to the furnace. The usual material charging rate to the furnace is 1-1/2 to 2 tons/min when the slinger machine is in operation. About 700 tons of charge (of which about 94 percent is concentrate) is fed to the reverberatory furnace per day. Table 1 presents a typical material charge. The elapsed time between charging the furnace to tapping the matte is usually 4 hours. Approximately 30 to 36 taps are made per cycle. The furnace has three matte tapping holes (two operate at a time), and one slag tapping hole. The matte is tapped into laddles, picked up by overhead cranes and are charged to one of three converters. Usually two converters are kept hot (one operates at a time). The converter cycle time is roughly 6 hours. The number of converter chargings corresponds to the number of tappings.

Exhaust gases from the reverberatory furnace pass through a pair of waste-heat boilers, then enter a balloon flue and a common plenum chamber for the two independent, parallel, electrostatic precipitator units. A heavy load of dust is accumulated on the waste-heat boiler walls. The dust is removed from the walls every 2 hours by the use of soot blowers. The waste-heat boilers do not contain radiant cooling sections, these are required to recover heat from flue gas generated by smelters using coal as fuel. The gas collection system was designed orignally so that 50 percent of the gas stream from the electrostatic precipitator could be directed through the DMA SO_2 absorption plant, and the remaining 50 percent could be exhausted to the stack. However, at present the duct arrangement for the gas stream going to the DMA plant is completely cut off, so the entire gas stream from the precipitator is exhausted through the stack. An ID fan installed downstream of the precipitator moves the gases through the stack. A flip-flop damper is installed in the duct system so that the gases can be guided either through the balloon flue or the duct work.

The reverberatory furnace matte and slag tap areas are hooded, and the collected gases containing particulate matter are exhausted directly to the smelter main stack.

The acid plant is not operating, but it is being kept in operating condition by continuously checking for leaks and material corrosion.

Any heavy particulate material dropped out in the waste-heat boiler is recycled back to the converter; and the fine dust,

Table 1. MATERIAL CHARGE TO THE REVERBERATORY FURNACE ON JUNE 15, 1977

Material*	Amount
Concentrate	636
Precipitates	9
Lime rock	31
Flue dust from reverberatory furnace	7
Reverts	7
Flue dust from converter precipitator	6

* In addition, 341 tons per day of converted slag is added. Metallurgical Department of Phelps-Dodge Copper Company has analyses of individual material changed. The data can be obtained on request.

depending on the quality, is recycled back to the reverberatory furnace or the concentrator. Dust collection in the waste-heat boilers is up to 6 tons per day on vertical tubes; the amount collected on water wall sections is not known. Analysis of the dust collected in the waste-heat boiler hopper is available on a monthly composite basis.

According to Mr. Rickard, the furnace design is not suitable for using pelletized converter slag as is the practice at Kennecott Copper Company. In his opinion, converter slag is used in the reverberatory furnace primarily for charge recovery purposes and may not improve environmental conditions.

Because the converter operation is exothermic, it is essential to burn all the silica in the converter. For this reason the heavy particulate from waste-heat boilers is charged to the converters.

Mr. Rickard expressed that the flip-flop damper, the manholes on the ESP, and the access doors to the hoppers are possible sources of air infiltration. The expansion joint on the downstream side of the ID fan failed this year and was a source of air infiltration. The reason for the difference in measured velocity through the two ducts could be due to size differences in the hanging dampers installed in each duct.

Corrosion problems are being experienced from the electrostatic precipitator on the converter, usually when the flue gas temperature is lower than 465°F, because of formation of sulfuric acid.

Mr. Rickard does not know if the two new mist precipitators installed can be utilized as add-on equipment to treat reverberatory furance gases.